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AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM).

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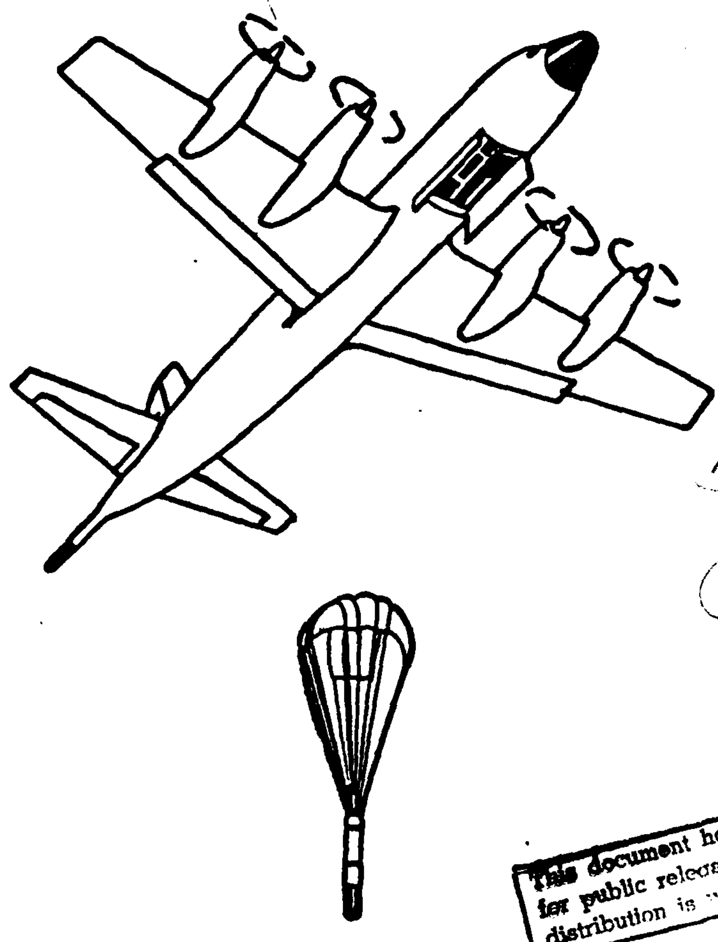

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28 Feb 80

MARINE SYSTEMS ENGINEERING LABORATORY

UNIVERSITY OF NEW HAMPSHIRE
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EXECUTIVE SUMMARY

The purpose of this document is to present the technological accomplishments in the arctic portion of the Air Deployed Oceanographic Mooring program during 1979. Technology is currently being developed for the unmanned deployment of oceanographic sensors from an aircraft into the world's ice covered polar oceans.

During 1979, the second year's major milestones were met and include:

- Full scale model testing of the recirculating water jet drill conducted at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH.
- Completion of the Concept Validation Model (CVM) ice drill design.
- Completion of the CVM ice drill fabrication.
- Initiation of the CVM ice drill testing program at CRREL.
- Testing of lithium battery cells subjected to high rate discharge.
- Review of sea ice structure and arctic pressure ridge distribution and their impact on the ADOM landing system.
- Review of potential techniques and selection of a preferred ADOM landing system.
- Completion of the conceptual design for the Advanced Development Model (ADM) arctic ADOM system.

Key findings from the past year's efforts include:

- Model testing verified that approximately 37 KWHR of electrical energy is required to penetrate 15.2 m of ice with a 15 cm diameter hole. 26 KWHR is required to penetrate 10.6 m of ice.
- The recirculating water jet drill is an effective and thermally efficient ice penetrating system and well adopted to unmanned computer controlled operations.

- Lithium batteries are presently the best energy source available and drill speed can be designed to match battery power output for greatest efficiency of energy transfer.

- A simple landing system can be devised to provide accessibility to more than 90% of the arctic ice cover.

- The DeHavilland Twin Otter, as well as the much larger C-130, can be used as the vehicle for air launching the arctic ADOM system.

1980 Plans

The planned actions for the arctic portion of the ADOM program during 1980 are as follows:

- Completion of testing the CVM ice drill at CRREL

- Completion of control system software and computer development.

- Fabrication of two ADM ice drills with subsequent testing at CRREL.

- Completion of landing system design and development with limited drop tests.

- Energy system development and interfacing to ADOM lander.

- Initial interfacing of all system components.

SECTION I

INTRODUCTION

1.1 PURPOSE

This document presents the technological accomplishments in the arctic portion of the Air Deployed Oceanographic Mooring (ADOM) Program during 1979.

1.2 BACKGROUND

Technology is currently being developed for the unmanned deployment of oceanographic sensors from an aircraft in two regions of the world's oceans; the open ocean and the polar seas. A wide variety of scientific investigations can be pursued with air deployed oceanographic moorings which can be configured to meet specific scientific requirements. Two corresponding systems are being developed to meet these scientific needs; an open ocean ADOM and an arctic ADOM. It is this arctic ADOM program which is the prime responsibility of the Marine Systems Engineering Laboratory (MSEL) of the University of New Hampshire.

Both systems share in common the data acquisition and telemetry electronics, sensor system, and decelerator assembly, but differ substantially in all other system aspects.

The contributions made in 1979 represent MSEL's second year effort in the ADOM program. The first year's effort include the following completed milestones:

- A statistical description of the thickness of sea ice to be penetrated.
- A review of the technologies and the techniques that might be employed for an unmanned air deployed drill.
- The generation of decision rules for system selection.
- Identification of a preferred system.

- Initial testing to verify the performances of the preferred system.

- Planning for the design and fabrication of a Concept Validation Model (CVM) to be completed in the second year.

SECTION II

FINDINGS

2.1 GENERAL

The Arctic ADOM system, when deployed, is shown in Figure 2-1. It consists of the landing structure on the ice, a 1000 meter sensor cable, and an ice drill at the end of the sensor string. The electronics and telemetry systems are located in the landing structure.

Necessary for the design of a system with a high probability of success is a thorough understanding of statistical extent of not only the thickness, but also of the sea ice structure, including internal and surface texture. Section 2.2 is a review of sea ice structure and its impact on the ADOM system design. The present design for the ice penetrating drill system is presented in Section 2.3 and the influence of sea ice structure is clearly evident in this design. Paramount to the success of the arctic ADOM program was the establishment, early in the program, of the validity of the concept of a recirculating water jet drill as an effective technique for penetrating the ice surface, as predicted by the computer model developed in the first year's efforts. Section 2.4 presents the program which was conducted at the U.S. Army Cold Regions Research and Development Laboratory, Hanover, NH, to verify the drill's performance. A preliminary study was conducted by EG&G on the deployed sensor string configuration, the results of which are discussed in Section 2.5. Landing system alternatives and the chosen preferred system are discussed in Section 2.6. Making arctic ADOM an autonomous system requires an intelligent and simple control and sensor system. Section 2.7 presents the conceptual design for the computer control system. Further investigations were conducted into the energy system

and these are presented in Section 2.8. Since the polar ice pack is known to be dominated by two distinct but varying drift patterns, as discussed in Section 2.2, it becomes necessary to provide a means for determining arctic ADOM geographical position through time. These navigational considerations are discussed in Section 2.9. Conclusions drawn from this second year's efforts are presented in Section 2.10.

2.2 REVIEW OF SEA ICE AND PRESSURE RIDGE CHARACTERISTICS

The following sections have been extracted from notes prepared June 4, 1979. Refer to reference 1.

2.2.1 STRUCTURE OF SEA ICE

The brine pockets which form in newly developed sea ice affect the strength of the ice, however these brine pockets do not appear to pose any significant detriment to the drilling system chosen for ADOM. As the newly formed ice thickens and ages, the entrapped brine gradually drains down and out of the ice through brine drainage channels. Near the bottom of thick annual sea ice, these drainage channels appear to occur in about 15-20 cm horizontal spacings and have diameters of approximately 1 cm. (See Figure 2-2). As the ice undergoes its first summer melt, fresher surface melt water drains through the ice flushing even more brine down and out, and solidifying and strengthening the remaining ice.

First year ice is thin (0-2m) and is the result of one winters ice growth. Multiyear ice is thicker (2-4m), and having gone through at least one melt season, is low in brine, low in temperature, and high in strength.

ARCTIC ADOM MOORED SYSTEM

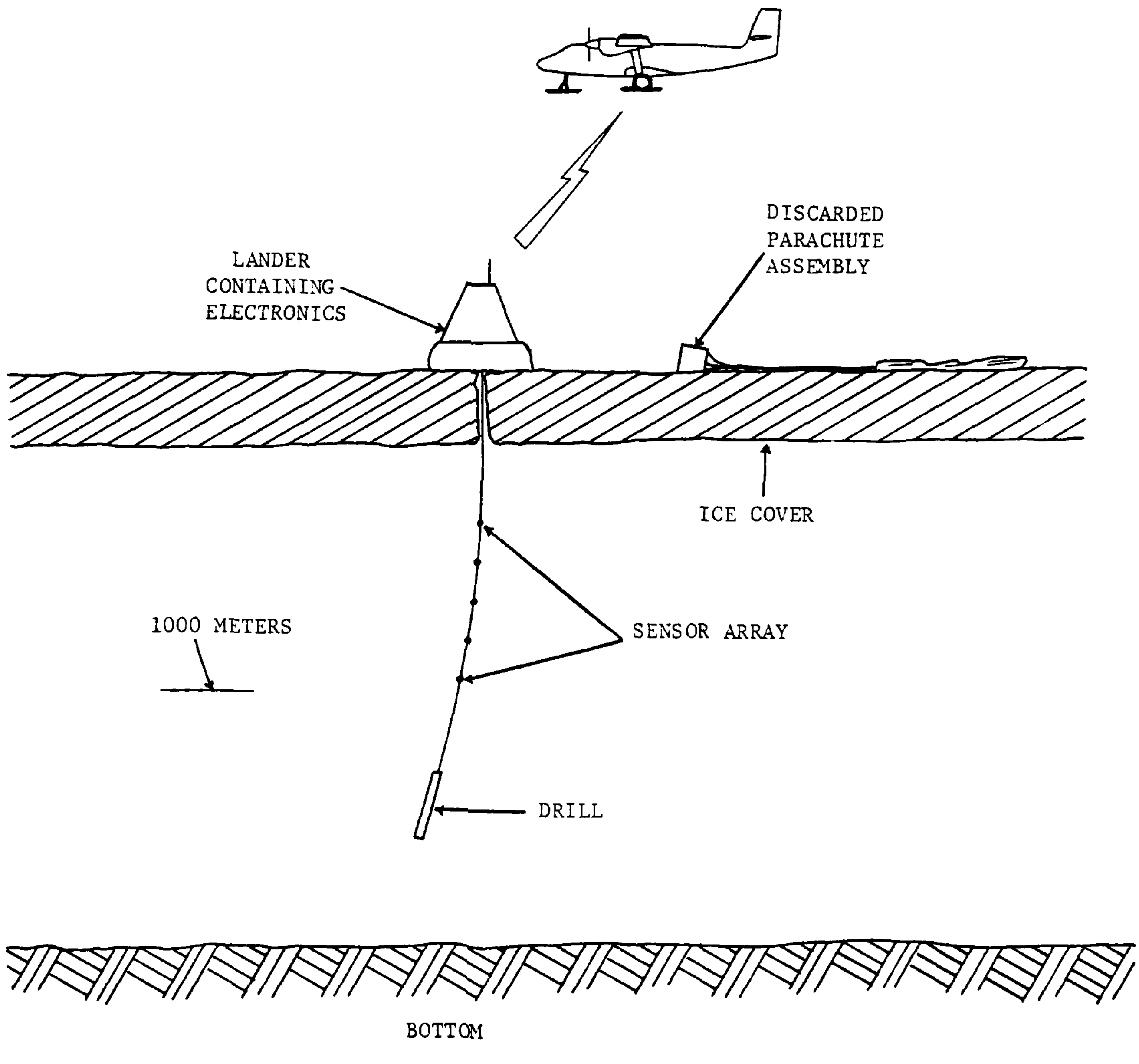
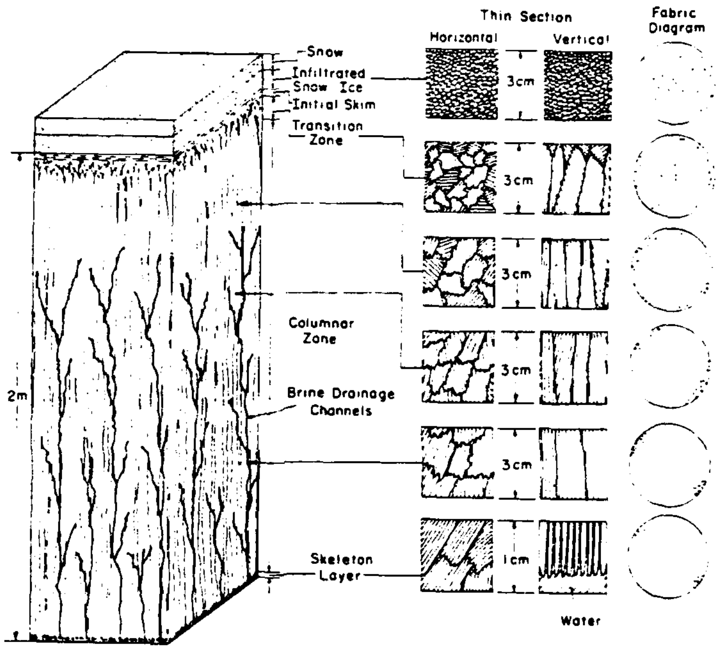


Figure 2-1

STRUCTURE OF FIRST YEAR SEA ICE



Schematic drawing showing several different aspects of the structure of first-year sea ice.

Adapted from Schwarz
Refer to Reference 1.

Figure 2-2

2.2.2 LEADS AND PRESSURE RIDGES

Leads form when cracks develop in the ice producing areas open to sea water. The percent of arctic topography, which is covered by open leads, can vary from 1 to 9 depending on season and location. Within a few hours, these leads begin to freeze over with as much as 30 cm of ice forming in 5-15 days. As these cracks close in, the newly formed thinner ice is forced into pressure ridges. The resultant ridging which occurs will vary and is dependent on the relative thickness involved and the local motion (compression or shear).

The majority of pressure ridges are formed from thin first year ice. Newly formed, first year ridges consist of randomly packed, unbonded chunks of ice. Above and below sea level, voids exist and the porosity can be approximated at 30%. Voids below sea level generally fill with sea water and begin to refreeze. Voids in the ridge sail fill slowly with snow, and strong interblock bonding is a slow process, especially in winter. As first year ridges undergo the transformation to multiyear ridges by surviving their first melt season, the internal and surface structure of the ridges is vastly altered. Since the upper levels of the ridge are low in salinity, the melt water produced during the summer season is essentially fresh. As the ridges melt, the jagged ice chunks become rounded and melt-water begins filling the voids and brine channels, displacing the more dense sea water below sea level. At the end of the melt season, the ridges begin refreezing and forming hard, strong cores with few voids.

2.2.3 DISTRIBUTION OF PRESSURE RIDGES

At its maximum extent, Arctic sea ice covers approximately 15.1×10^6 km^2. Most of this ice and the thicker multiyear ice is in the land locked Arctic Ocean and marginal seas. Because of land locked nature of the Arctic Ocean, the ice extent seasonal variation is 20-25% of the maximum.

Based on data from BIRDSEYE flights, the Arctic Ocean can be separated into 3 provinces:

1. Coastal Province (Alaskan Coastal) - This zone consists of shore fast ice bordered by a flaw zone of disturbed ice and in some locations a recurring flaw lead.

2. Offshore Province (along North coast of Greenland and Canadian Archipelago) - Primarily composed of relatively unstable first year ice with considerable deformation. Hummock fields are particularly common.

   In spring the distinction between the first two provinces vanishes with the breakup of fast ice and a melting of a great majority of the first year ice located near the coast.

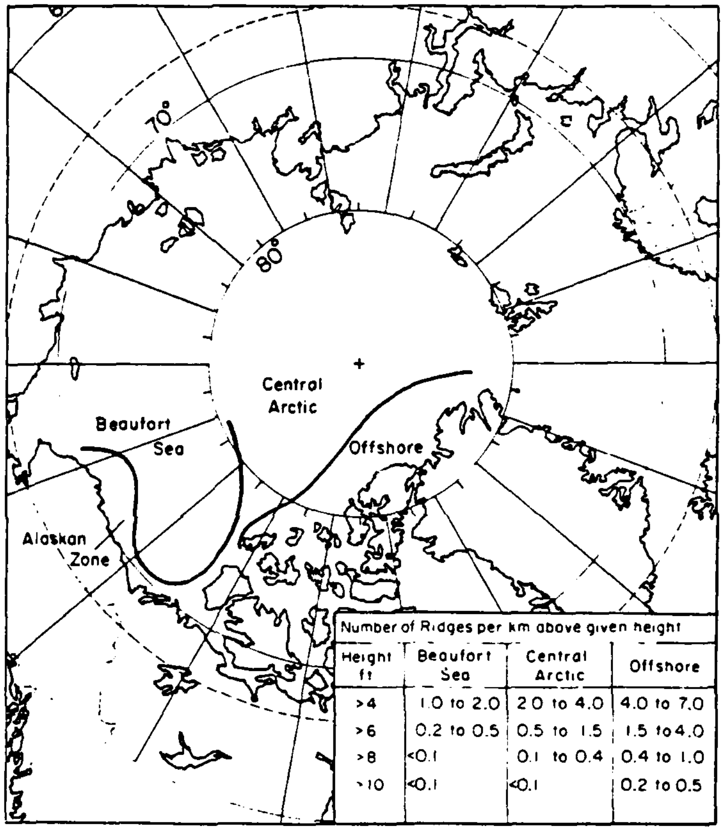
3. Central Arctic Basin Province - largest province, mostly multi-year ice.

These 3 regions can be defined in terms of ridging intensity, where ridging intensity is uniquely determined (for a given province or region and season) by the mean number of ridges per unit length above a given height and by the mean ridge height. Year to year variations in ridging are significant, but relative ridging intensities and boundaries between regions remain similar. (See Figure 2-3).

Coastal Province

Two types of ridges are expected to be quite frequent near the edge of fast ice; grounded ridges and shear ridges. As pressure ridges develop in deeper water, they become grounded in shallow water and sails can become very high as snow accumulates and ice is piled on (heights of 30m have been reported north of Greenland and the Canadian Archipelago).

REGIONAL VARIATION OF RIDGING



Height ft	Beaufort Sea	Central Arctic	Offshore
Number of Ridges per km above given height			
>4	1.0 to 2.0	2.0 to 4.0	4.0 to 7.0
>6	0.2 to 0.5	0.5 to 1.5	1.5 to 4.0
>8	<0.1	0.1 to 0.4	0.4 to 1.0
>10	<0.1	<0.1	0.2 to 0.5

Regional variation of ridging in the Arctic Basin, given in terms of number of ridges per kilometer above different heights.

Adapted from Sterrett
Refer to Reference 1

Figure 2-3

The northern edge of the Coastal Province is marked by a flaw lead at the boundary of fast ice and pack ice. Leads open and close as the pack moves. Leads can be up to several nautical miles wide at its maximum width in winter. Leads are covered quickly with new ice which readily deforms when the pack moves, producing small pressure ridges.

Offshore Province

Based on data from BIRDSEYE, 26% of the Offshore Province area contains either hummocks or ridges in the winter. Sonar profiles have shown zones several hundred km's wide which were more than 50% covered with hummocks. (Table 2-1). One large field was observed in the Chukchi Sea covered by more than 50% with hummocks which reached heights of 7m.

During the summer, ice conditions are variable. Pack boundaries range from near shore to over 200nm offshore. In summer, the number of ridges per nautical mile is greatly reduced, most probably due to melting and collapsing of the ridges.

During the peak of the melt season, up to 60% of the surface of drifting ice is covered with melt ponds, many of which are deep and some perforating the ice cover.

Limited information suggests that floes in the Offshore Province are smaller than ice farther north and that rubble fields and areas of brash ice are particularly common.

Ridges exceeding 4m (13.1 ft.) are not common.

Central Arctic Basin Province

Multiyear ice is the predominant feature in the Central Arctic Basin. Most of the ridges are formed from the thinner first year ice. (Table 2-2).

Pressure ridges in the Central Arctic Basin have generally undergone several melt seasons and thus are hard, solid structures with slopes less than 30°. This is in contrast to the first year ridges found in the Offshore province which are poorly bonded chunks of ice.

The one parameter model for sea ice ridging (γ_h - ridging intensity) is extremely useful when used with a graph showing average number of ridges per km, μ_h above any given height h versus the square root of ridging intensity (Figure 2-4). Regional and seasonal variations of ridging intensity is given in Figure 2-5. From Figure 2-5, it can be seen that be far, the Offshore Province is the highest ridge province. Ice surface coverage for the permanent pack is illustrated in Figure 2-6 along with the approximate areas bounded by the three provinces and the 0 to 180° longitude lines. Considering the relative areas and ridging, it is estimated that the Arctic ADOM can safely land in over 90% of the arctic.

ICE CONDITIONS IN THE OFFSHORE PROVINCE

SOURCE	SUBJECT		SEASON	
			WINTER	SUMMER
BIRDSEYE	Concentration (areal, %)	average	99	78
		range	70-100	8-100
	Ice types (areal, %)	young	7	5
		winter	46	46
		multi-year	46	27
	Topography (areal, %)	large ridges and hummocks (>3 m high)	21	15
		small ridges and hummocks (<3 m high)	5	8
	Number of water openings	>30 m/100 nm	34	76
		<30 m/100 nm	134	73
Submarine	Topography (linear, %)	openings	2	9
		ice	98	91
		keels	12	7

Adapted from Weeks
Refer to Reference 1.

Table 2-1

ICE CONDITIONS IN THE CENTRAL ARCTIC BASIN PROVINCE

SOURCE	SUBJECT		SEASON WINTER	SEASON SUMMER
BIRDSEYE	Concentration (areal, %)	average	99	92
		range	98-100	30-100
	Ice types (areal, %)	young	1	4
		winter	17	27
		multi-year	81	61
	Topography (areal, %)	large ridges and hummocks (>3 m high)	21	23
		small ridges and hummocks (<3 m high)	4	4
	Number of water openings	>30 m/100 nm	23	39
		<30 m/100 nm	33	53
Submarine	Topography (linear, %)	openings	1	5
		ice	99	95
		keels	15	15

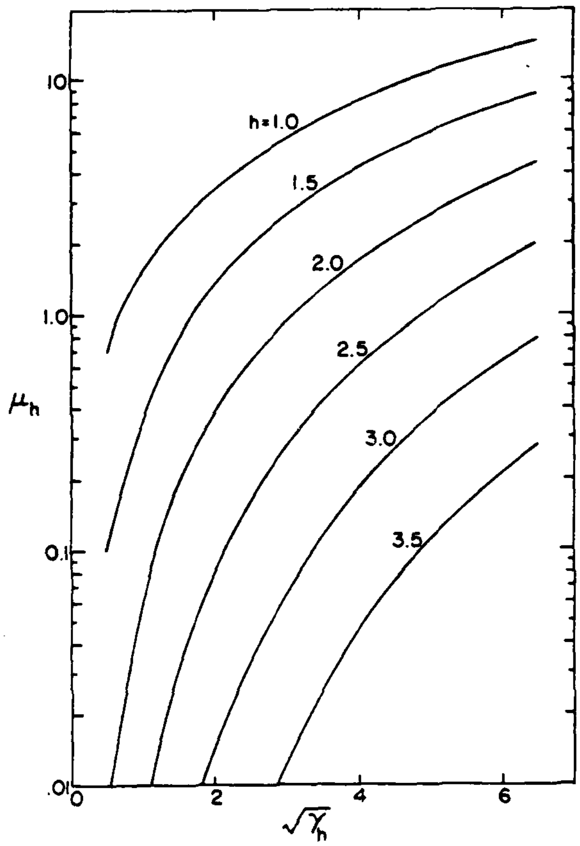
Adapted from Weeks
Refer to Reference 1.

Table 2-2

AVERAGE NUMBER OF RIDGES PER KILOMETER

vs

THE SQUARE ROOT OF RIDGING INTENSITY

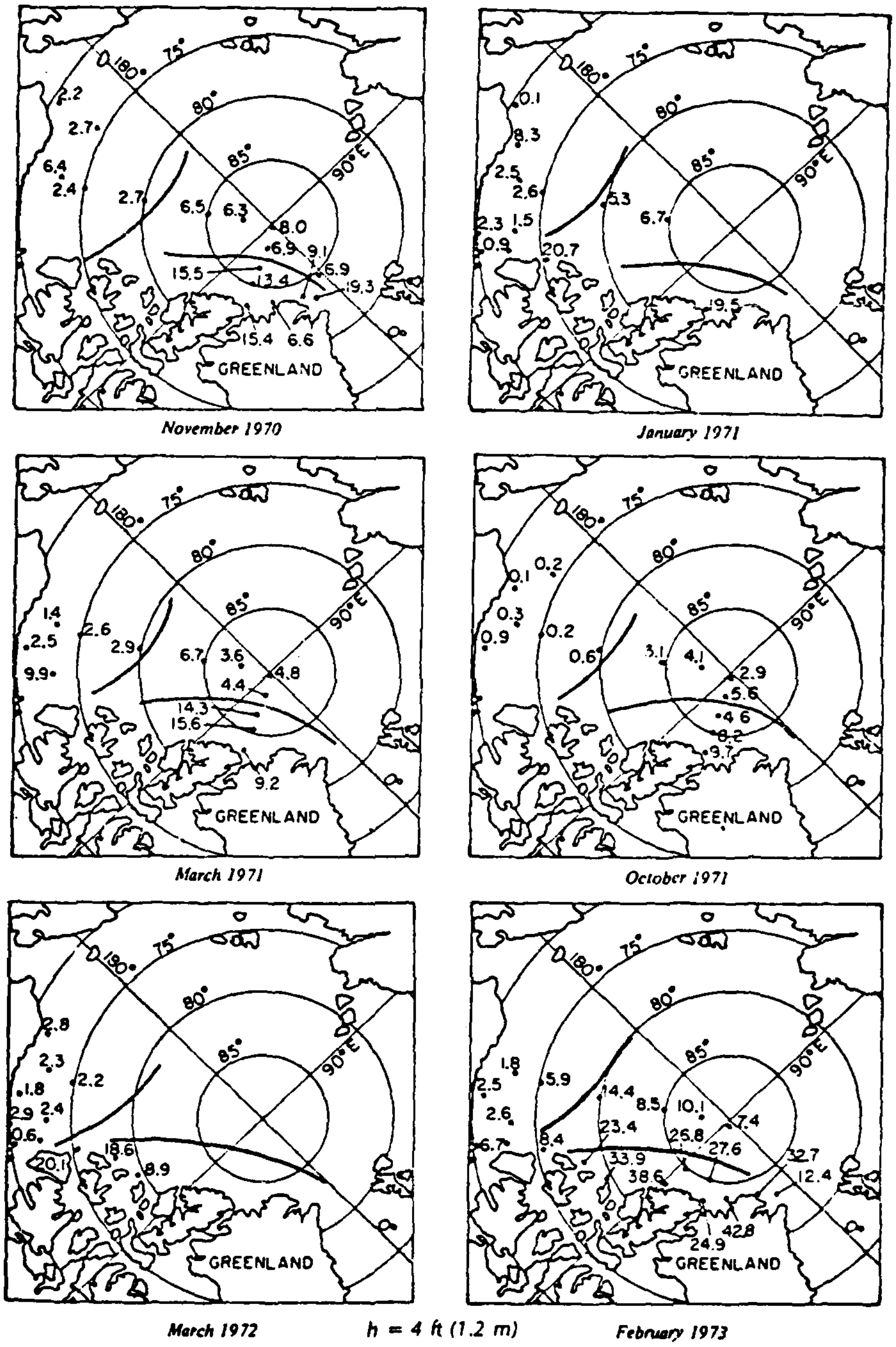


Average number of ridges per kilometer μ_h above any given height h vs the square root of ridging intensity γ_h.

Adapted from Sterrett
Refer to Reference 1.

Figure 2-4

REGIONAL VARIATIONS IN RIDGING INTENSITY IN FALL AND WINTER, 1970 to 1973

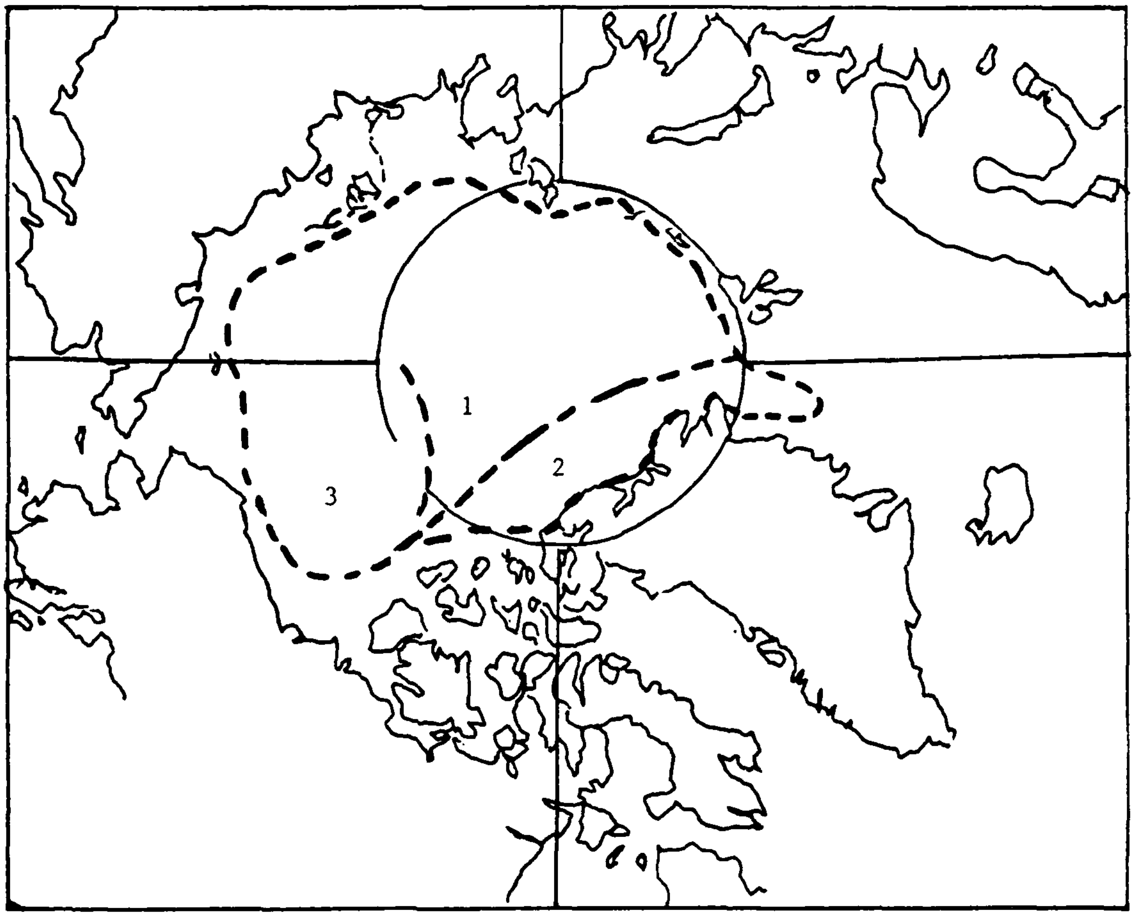


Regional variations in ridging intensity γ_h (m^3/km) in fall and winter, 1970 to 1973.

Adapted from Sterrett
Refer to Reference 1.

Figure 2-5

AREAL COVERAGE OF ARCTIC ICE PACK



SECTION 1	194,000	Square Miles
SECTION 2	453,000	
SECTION 3	501,000	
TOTAL	1,148,000	

Figure 2-6

2.2.4 ARCTIC ICE DRIFT PATTERNS

Two dominant drift features are evident from Figure 2-7. The first feature is the Transpolar Drift Stream from East Siberian Sea across the North Pole to northeast of Greenland. The source for this ice is from the cold shallow water off the Siberian Continental Shelf. Because this area is ice free in summer, it undergoes rapid ice growth every fall. This area also has areas of thin rapidly growing ice even in winter due to the northward movement of the ice.

The transpolar trip takes about 5 years to complete. Ridges and hummocks still show some angular outline and the undisturbed ice reaches its maximum thickness of approximately 3m.

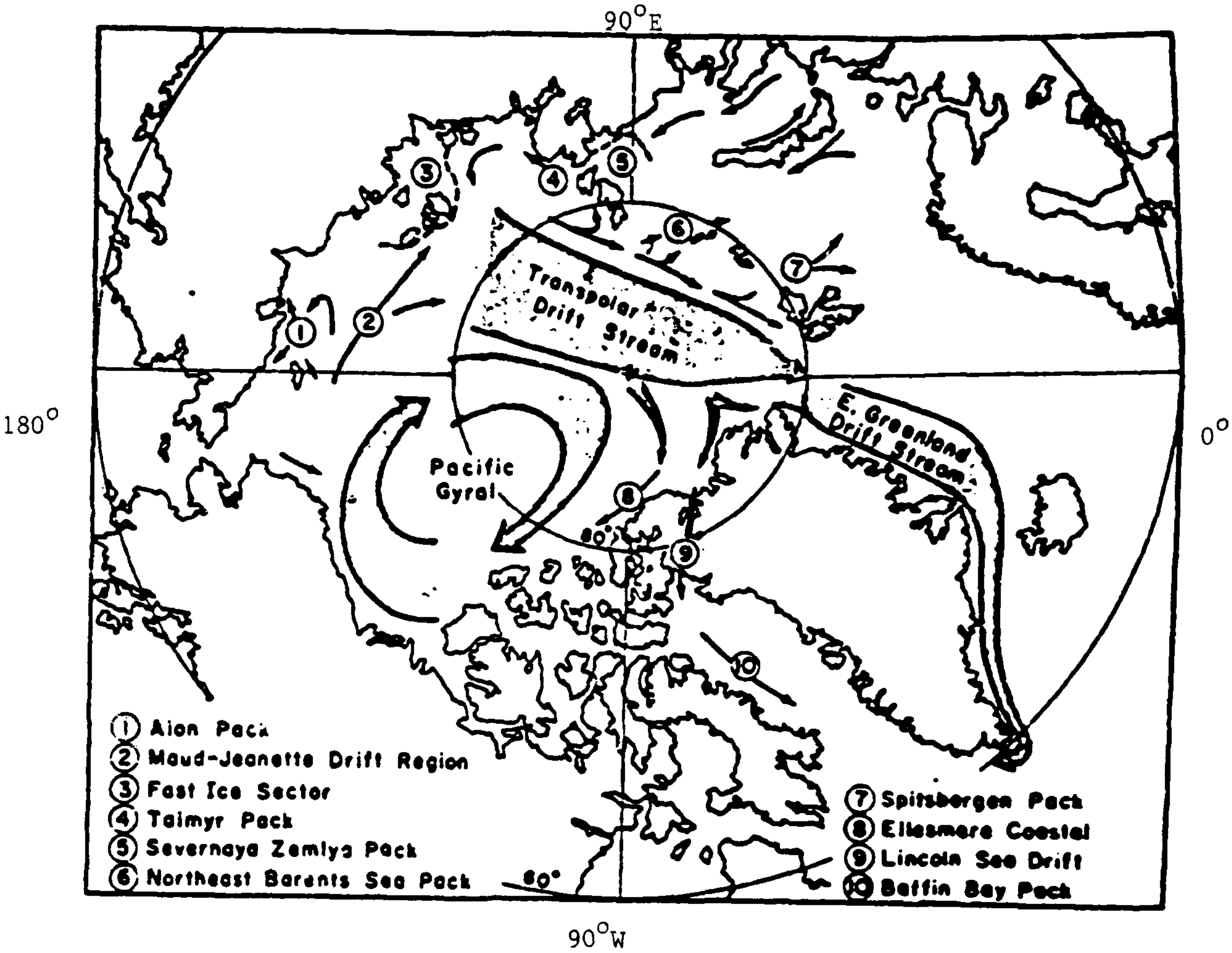
The second major drift feature is the Pacific Gyral. It is a region of generally closed clockwise drift located between the Canadian Archipelago, and Alaskan north coast and the North Pole. Here the oldest and heaviest ice is present. Floes have been known to last in the gyre for more than 20 years. The boundary between the two gyres is marked by a change in topography and varies in geographical position from year to year.

The principle exit for ice from Arctic Ocean is via the East Greenland Drift Stream. Consequently the most intense ridging in Arctic Ocean occurs just off the coast of northeast Greenland, where the ice that splits away from the Transpolar Drift Stream to move westward to rejoin Pacific Gyre is forced to turn the corner by the blocking effect of Greenland.

Mean drift rates for the ice pack varies from 0.4 to 4.8km per day. Monthly average values may be as high as 10.7km/day.

The surface of the ice near the southern edges of the pack are very rough and the floes have been broken up and reduced in size, presumably by wave-induced fracturing.

MAJOR DRIFT PATTERNS OF ICE IN THE ARCTIC OCEAN



Adapted from Weeks
Refer to Reference 1.

Figure 2-7

2.2.5 CONCLUSIONS

Conclusions based on the review of sea ice and pressure ridge characteristics are summarized as follows:

- Sea ice characteristics do not appear to pose a significant detriment to the hot water jet drilling operation.
- Ice ADOM will have to land on pressure ridges
- Multiyear pressure ridges do not appear to pose significant problems to ADOM's landing, drilling, and data transmission operations.
- First year pressure ridges will have a significant impact on ADOM's landing and drilling systems and a small impact on data transmission operation:
  - ice chunks are of similar dimensions as Ice ADOM
  - poor interblock bonding
  - high degree of porosity within the ridge
  - higher brine volume, thus lower resistivity
- It is estimated that only 10% of the total Arctic ice coverage will pose a serious threat to a successful ADOM landing due to pressure ridging. The bulk of this 10% is located within the Offshore province, the area of greatest ridging intensity. In this area, pilot discretion in launching Arctic ADOM will reduce the possibility of landing in areas of severe ridging.
- Mean wind speeds in the basin do not appear significant.
- Ranking of the three provinces in order of increasing impact on Ice ADOM.
  - Central Arctic Basin Province does not appear to pose a significant impact primarily because the pressure ridges are multiyear and ridging intensity is low.
  - Alaskan Coastal Province will have an impact although ridging intensity is low primarily because this is a zone of disturbed ice (new ridge formations).
  - Offshore Province will have a significant impact due to large ridging intensity, first year ice and ridges. Potentially, 1 in 4 ice ADOM's could land on these pressure ridges.

2.3 THE RECIRCULATING WATER JET DRILL

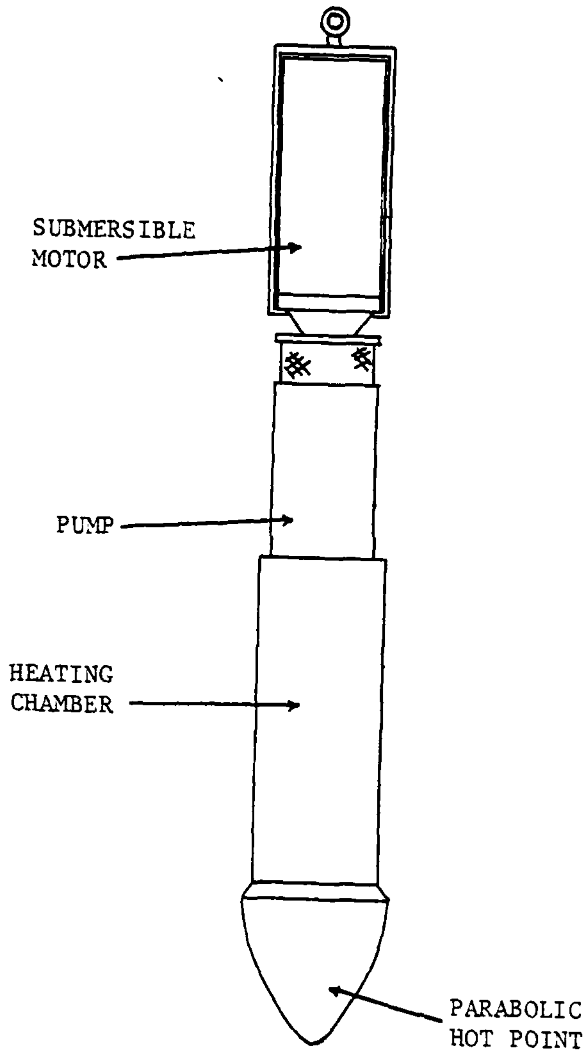
The CVM ice drill design is illustrated in Figure 2-8 and is composed of the following main components:

- Parabolic hot point
- Internal heating chamber
- Internal axial pump
- Submersible motor
- Power and sensor cable assembly

During the jet drilling phase, water heated internally in the drill, is pumped out the end of the drill at high velocity through a nozzle, striking and melting the ice below. As melt water develops, it is continuously recirculated into the drill and pumped out as a warmed jet stream. The jet stream significantly increases the transfer of heat energy from the water to the ice than could be achieved through conduction and/or natural convection.

The ADM drill design is similar to the CVM with the addition of a computer control electronics and tensiometer assembly mounted directly above the motor in a water tight case. Figure 2-9 illustrates the ADM ice drill design and Table 2-3 lists the preliminary drill specifications.

ARCTIC ADOM ICE DRILL - CVM



Detail of heating system

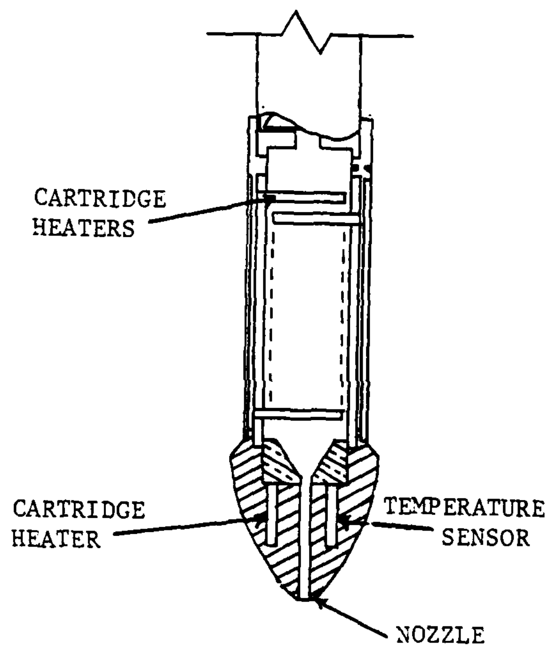


Figure 2-8

ARCTIC ADOM ICE DRILL - ADM

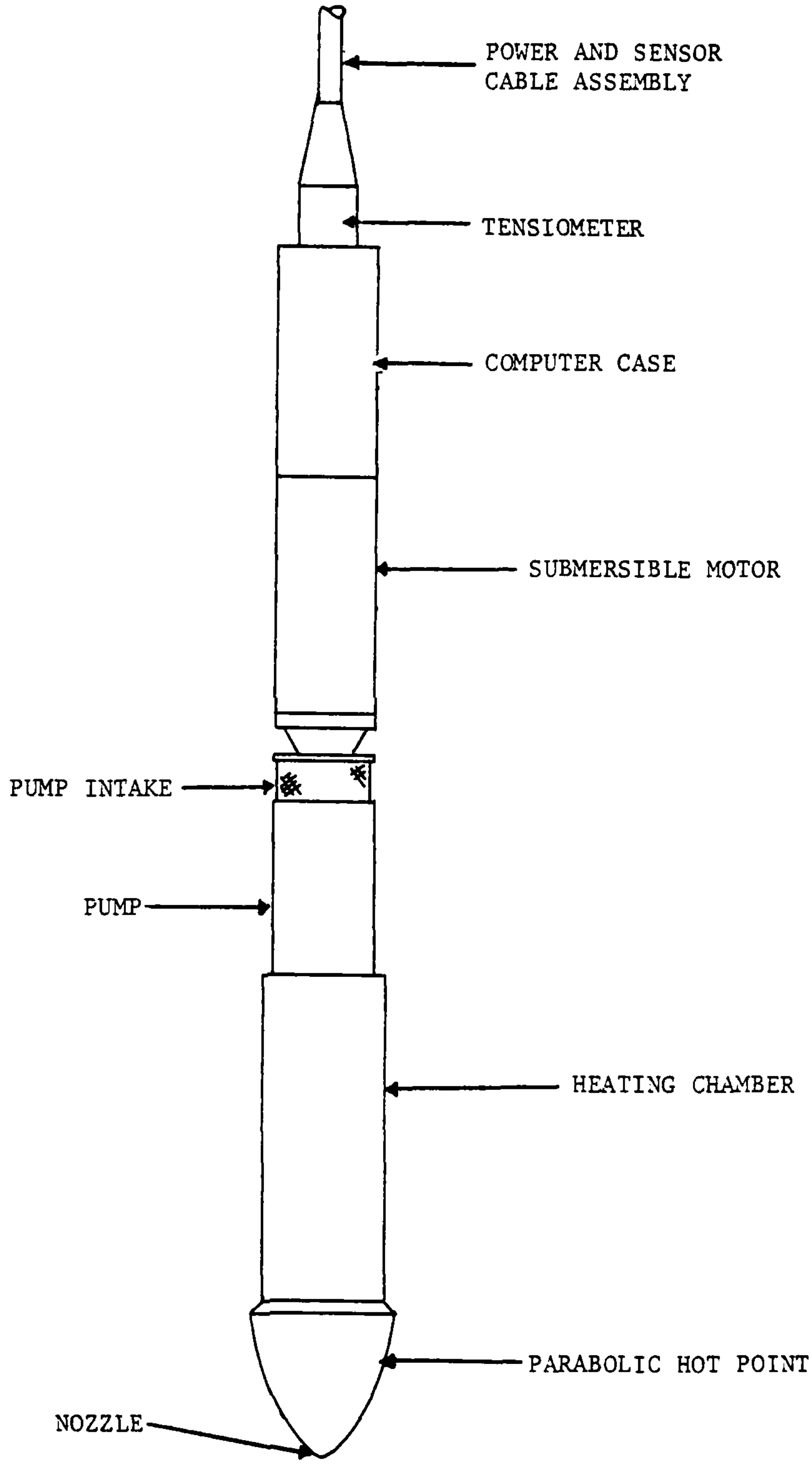


Figure 2-9

Table 2-3

	CVM	ADM
PUMP	3 STAGE 150 L/M	SAME
MOTOR	1.1 KW @ 220 VAC	SAME
HOT POINT	5 KW @ 350 VDC	NOTE 1
HEATING CHAMBER	36 KW @ 350 VDC	NOTE 1
LENGTH	1.35 m	1.5 m
WEIGHT IN AIR	37 KG	45 KG
WEIGHT IN WATER	28 KG	28 KG
CONTROL	MANUAL	MICROCOMPUTER

NOTE 1: Actual values will be determined during CVM testing at CRREL.

2.3.1 PARABOLIC HOT POINT

To begin the high efficiency jet drilling operation, recirculating water must be established in an adequate supply. The hot point provides this melt water by melting the drill into the ice until the pump is completely primed with melt water. Should the melt water supply be lost, as could happen by drilling into a large empty void, the internal pump can be reprimed through the melting and drilling action of the hot point. Another significant feature of the hot point is that it can serve as a backup drilling system, should the jet action fail, due to the unlikely event of clogging or local power failure.

The parabolic shape of the hot point is designed such that each section of the hot point melts the same amount of ice as all other sections (Hooke, 1974, Reference 2).

Electrical energy is added to the hot point through two parallel banks of high voltage cartridge heaters. These two banks allow control of power input and add redundancy to the system.

2.3.2 INTERNAL HEATING CHAMBER

Electrical energy is added to the recirculating melt water through the use of high wattage cartridge heaters located in the heating chamber. Cartridge heaters are mounted in 6 parallel banks which allow additional control of power input and add redundancy to the system.

2.3.3 INTERNAL AXIAL PUMP AND MOTOR

A standard deep well submersible pump and motor assembly modified to operate in the inverted position is used to provide the pumping action for the jet.

2.3.4 POWER AND SENSOR CABLE ASSEMBLY

All power and control lines for the CVM run from the drill to a control box located on the surface. In the ADM design, only power lines and one data line run between the surface and the drill as the control computer will be located insitu on the drill.

2.3.5 CONTROL OVERVIEW

Control of the CVM is manual, control of the ADM is via an onboard microcomputer. Control data is provided by temperature sensors in the hot point in both the CVM and ADM, by internal and external pressure sensors and a tensiometer in the ADM. Control is necessary to insure that the drill functions properly, does not overheat and adapts to the varying conditions of sea ice and pressure ridges. A more detailed discussion of the control system is presented in Section 2.7.

2.4 FULL SCALE MODEL TESTING OF THE JET DRILL

At the close of MSEL's first year effort in the ADOM program, a test plan was designed to model full scale the action of the recirculating water jet drill, Reference 3. The purpose of the experiment was to gain further insight into the heat transfer and power relationships of UNH's thermal drill. This data would not only serve to validate the computer model of the drill developed in the first year program, but also to establish early in the program, whether or not the jet drill was a workable and effective technique for penetrating the ice surface. A paper entitled, "Experimental Study of a Recirculating Water Jet Ice Drill" (Reference 4) is presently in preparation and describes the details of the experiment.

2.4.1 FACILITIES AND APPARATUS

Facilities at the U.S. Army Cold Regions Research and Engineering Laboratory were utilized for this experiment. Drilling was performed in a cylinderical ice sample, 1.8 m in diameter and 2.5 m in height, contained in a refrigerated steel tank (Reference 5). Figure 2-10 illustrates the test apparatus.

The model drill probe was constructed from standard PVC plumbing fixtures with minimal machinning required for the nozzles and internal check valve, see Figure 2-11. Nozzles were fabricated using standard PVC threaded pipe fittings which allowed rapid exchange of nozzle sizes. Simulation of the drill's internal heating chamber and pump were provided by an external 30KW immersion heater and centrifugal pump.

Flow measurements were provided using a Bendix Q series impeller mounted inside a 10cm PVC pipe, and temperature measurements were provided using thermistors for water temperature, and thermocouples for ice temperature.

Table 2-4 summarizes all the test runs.

TEST APPARATUS FOR FULL SCALE
MODELING OF THE
RECIRCULATING WATER JET DRILL

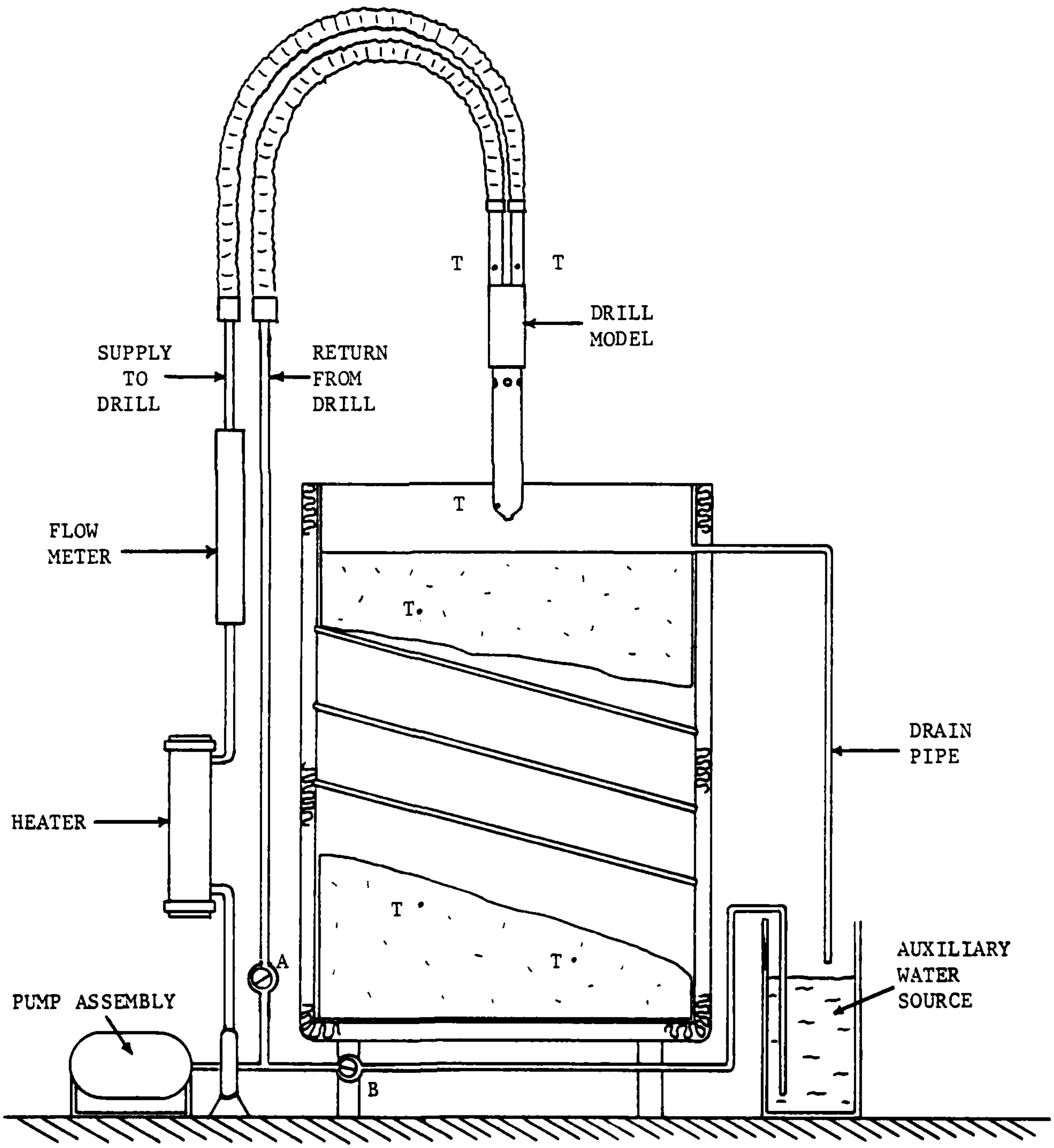


Figure 2-10

EXPERIMENTAL PROBE CONFIGURATION

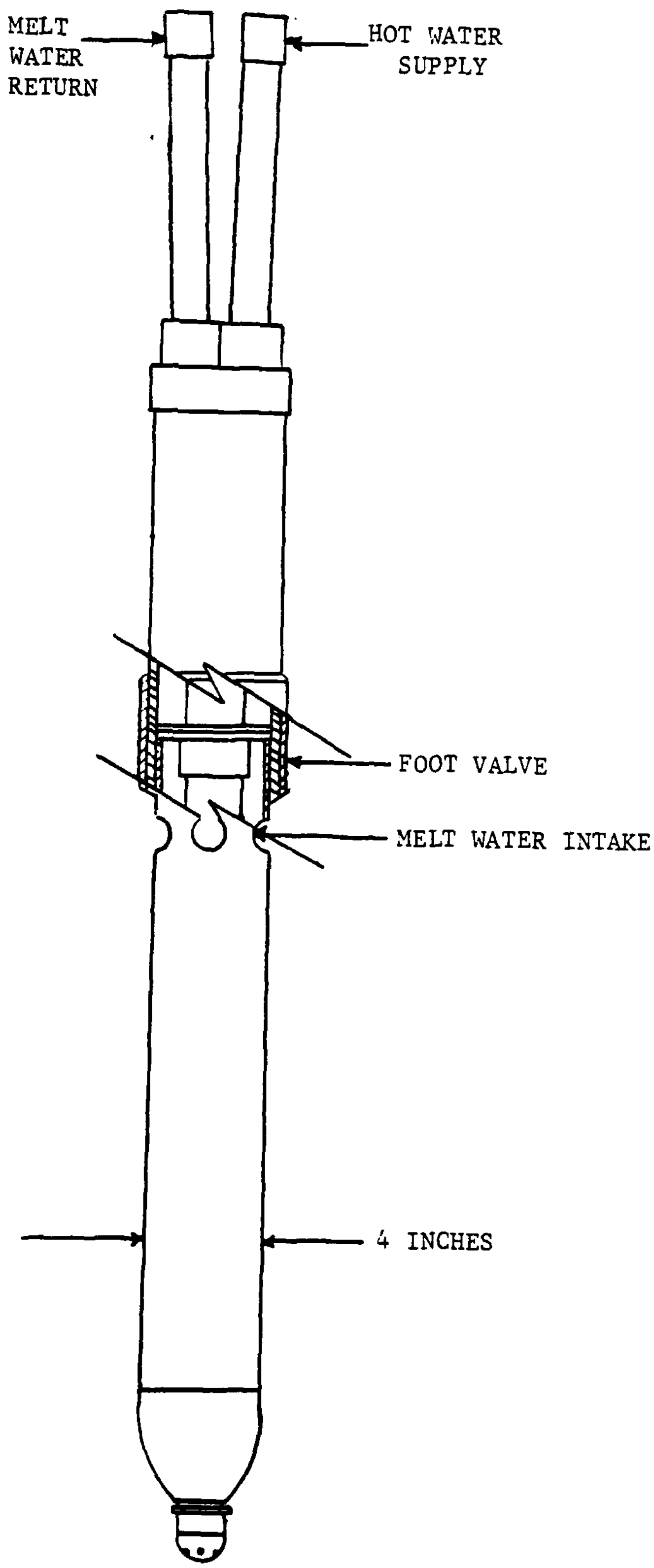


Figure 2-11

SUMMARY OF ICE DRILL VALIDATION TESTS

DATE	RUN	NOZZLE	POWER	FLOW	AVERAGE TERMINAL BULK TEMP.	AVERAGE TERMINAL DRILL RATE	ENERGY PER METER OF ICE	TOTAL ENERGY FOR 15M HOLE	REC. HEAT TRANSFER COEFFICIENT
		(mm)	(KW)	(LIT/MIN)	(°C)	(CM/MIN)	(KWH)	(KWH)	$CAL/cm^2 - S - ^oC$
3-8	1	12.7	SHAKE DOWN RUNS						
3-12	1	12.7							
3-12	2	12.7							
3-16	1[1]	9.5	-	104.1	-	-	-	-	-
3-16	2	9.5	20.7	98.79	9.5	14.6	2.36	35.4	1.81
3-16	3	9.5	19.9	99.17	9.1	14.7	2.26	33.9	1.91
3-16	4	9.5	19.8	84.41	9.2	13.6	2.43	36.4	1.72
3-21	1	12.7	20.6	173.4	7.0	16.3	2.11	31.7	2.71
3-21	2	12.7	20.4	68.51	13.2	14.9	2.28	34.2	1.38
3-21	3	12.7	21.2	64.72	14.9	14.7	2.40	36.0	1.19
5-17	1	TYPE 1	19.2	160.9	6.6	12.7	-	-	2.33
5-17	2	TYPE 1	16.6	159.4	7.5	12.0	-	-	1.99
5-17	3 [2]	TYPE 2	0[3]	162.4	-	-	-	-	-
5-17	4	TYPE 2	15.5	164.3	7.8	11.0	-	-	1.69
5-17	5	TYPE 2	16.0	159.7	4.9	9.7	-	-	1.66
6-18	1[3]	12.7	-	-	-	-	-	-	-
6-18	2	12.7	28.8	164.1	9.6	20.0	2.40	36.0	2.36
6-18	3	12.7	25.2	159.8	9.4	20.5	2.05	30.7	2.54
6-18	4	12.7	26.3	158.9	9.4	18.0	2.43	36.5	2.20
6-18	5	12.7	25.9	164.3	9.1	19.5	2.21	33.2	2.53
6-18	6	12.7	24.7	161.2	9.3	19.0	2.17	32.6	2.39
6-18	7	12.7	26.5	163.4	9.5	20.5	2.15	32.3	2.94
6-18	8	12.7	25.3	161.4	6.8	12.5	3.37	50.6	-
6-18	9	12.7	24.8	158.7	7.9	18.2	2.58	38.7	2.62
6-18	10[4]	12.7	12.9	145.3	5.7	8.5	2.53	38.0	-
7-17	1	12.7	13.0	154.5	6.0	14.5	1.49	22.41	2.92
7-17	2	12.7	12.5	138.2	5.0	11.0	1.89	28.41	2.67
7-17	3[3]	12.7	-	-	-	-	-	-	-
7-17	4[5]	12.7	-	-	-	-	-	-	-
7-17	5[3]	12.7	-	-	-	-	-	-	-
7-17	6[3]	12.7	-	-	-	-	-	-	-
7-17	7	0.953	13.0	95.8	6.9	11.9	1.82	27.31	2.07
7-17	8	0.953	13.9	97.48	7.0	11.5	2.01	30.22	1.98
7-17	9[3,7]	SHEATH	-	-	-	-	-	-	-
7-17	10[7]	SHEATH	-	-	-	-	-	-	-
7-17	11[6,7]	SHEATH	-	-	-	-	-	-	-
7-17	12[7]	SHEATH	-	-	-	-	-	-	-
COMPUTER		12.7	29.0	166.6	6.1	23.0	2.09	31.35	4.33

NOTES:
1. Flow meter failed, run aborted.
2. Radial nozzle design drilled a hole diameter greater than 15cm.
3. Pump lost prime, run aborted.
4. Pump clogged, run aborted.
5. Hit obstruction (eg. thermocouple chain).
6. Fire alarm, run aborted.
7. Drilled holes >>15cm rejected.
8. Value for the jet.

Table 2-4

2.4.2 RESULTS

Results of the experiment are listed below:

- Hole diameters of approximately 15cm were achieved as predicted.
- Terminal steady state drilling rate is proportional to power (Figure 2-12).
- Thermal efficiencies are high and average approximately 73%.
- Approximately 2.4 kilowatt hours of electrical energy are required to bore a 15cm diameter hole through 1 meter of ice. This represents 37 KWH for an ice thickness of 15m or 26 KWH for an ice thickness of 10.6m.
- Agreement with results of other experimenters (References 6 and 7), is good as shown in Figure 2-13. Indications are that increasing the nozzle diameter from 12.7mm to 16-19mm will improve the drilling performance and efficiency.
- Computer model predictions are within 10% of the physical test results.

2.5 PRELIMINARY ANALYSIS OF SUSPENDED SENSOR CABLE CONFIGURATION

Having defined the CVM recirculating water jet drill (Section 2.3), an analysis was performed by EG&G (refer to Reference 1), to predict the static configuration of the fully deployed sensor cable under varying current conditions.

The 1978 ADOM progress report (April 1979, Reference 8) defines two current profiles for Arctic ADOM (report Figure 1-2). One shows an Arctic ADOM suspended from fast ice (not moving), over a 51cm/s (1 knot) current centered at a depth of 150 m. The second assumes the ice is wind blown at a speed of 25.7cm/s (½ knot) against the sub-surface eddy. A third possibility is obvious - the wind blown floe in still water.

Cable configurations have been calculated for these three cases, assuming a drag coefficient of 1.2 for the 28.3 KG immersed-weight probe, and 1.8 for the 22.9 m of 1.27 cm power cable and the 1000 meters of 0.44 cm inch array cable. Drag of the sensor modules was neglected.

Four primary effects of the current are apparent:

1. to sway the probe horizontally from beneath the bore-hole in the ice,
2. to lift the probe above its maximum depth below the bore-hole,
3. to tilt the array from the vertical, and
4. to bend the array cable from a straight line.

These effects are summarized as follows:

CASE	CURRENT	SWAY (m)	RISE (m)	TILT (Deg)	BEND (Deg/1000M)
1	½ Kt Drift in still water	236.7	30.0	11	13
2	½ Kt Drift over 1 Kt eddy	289.1	52.5	18	27
3	0 Kt Drift over 1 Kt eddy	7.3	0.2	2	4

Figure 2-14 illustrates the configuration for the three cases.

Tables in Appendix A show the configuration and tension for the three cases as well as the input data used for the calculations.

DRILLING RATE vs POWER

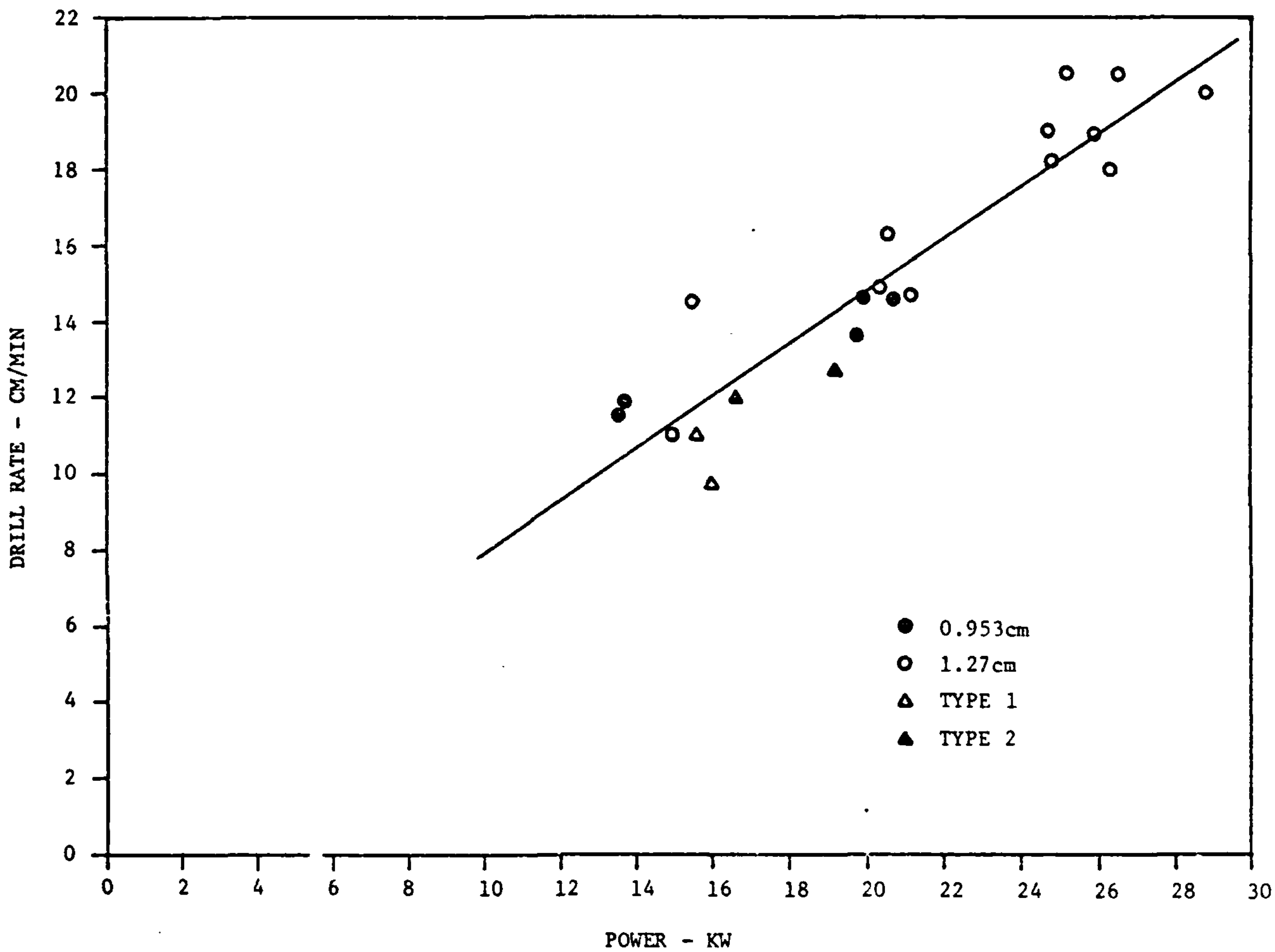


Figure 2-12

RELATIONSHIP BETWEEN Nu AND Re
FLUID PROPERTIES TAKEN AT 0°C

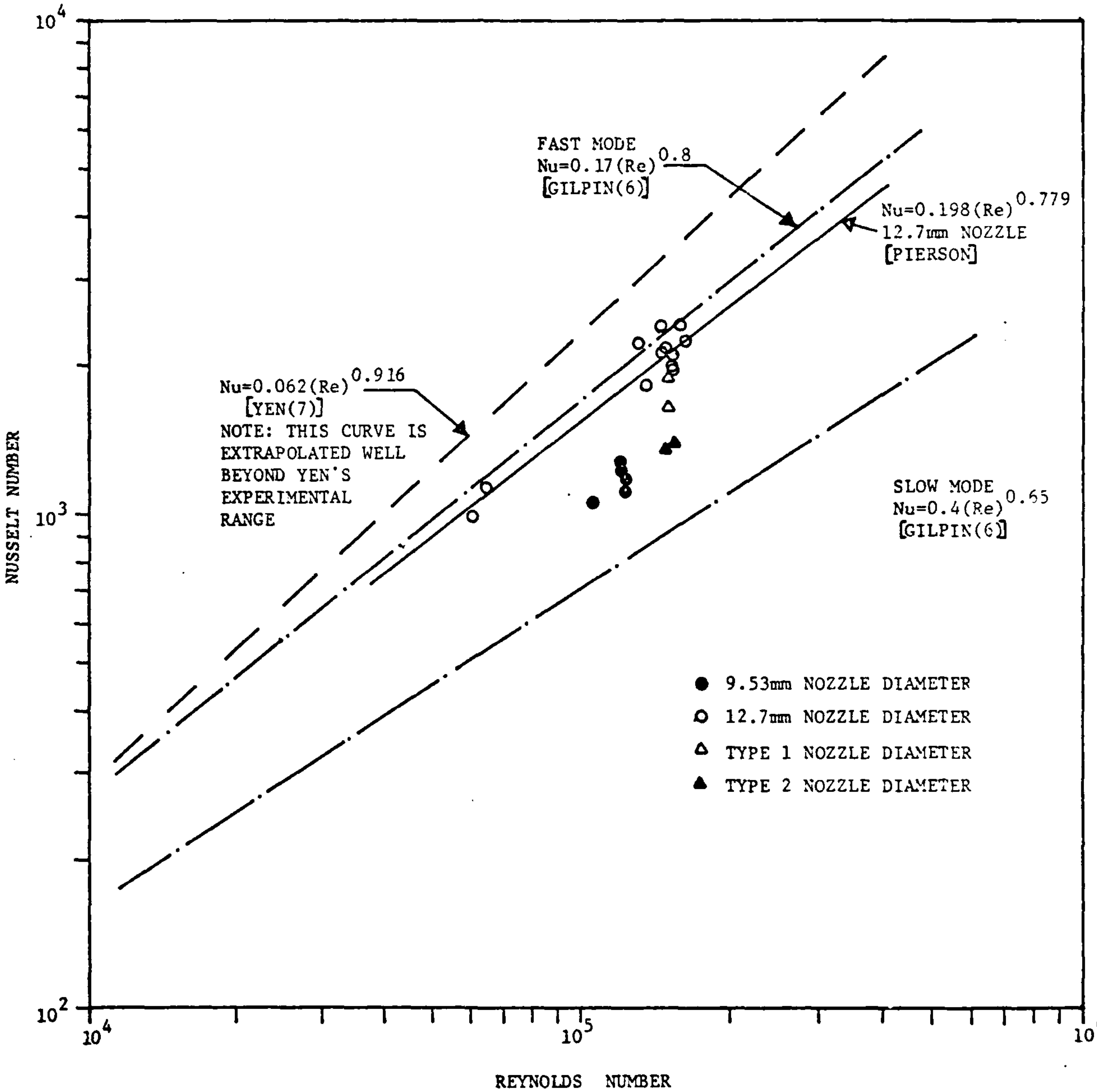
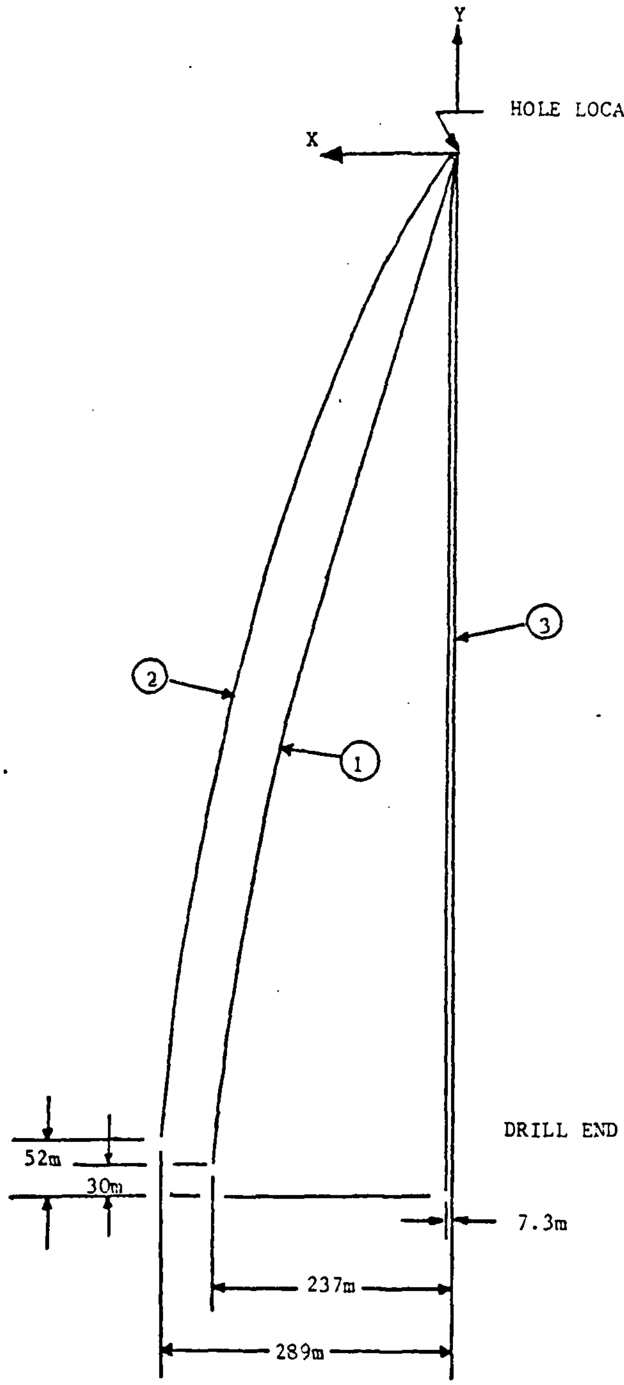


Figure 2-13

DEPLOYED SENSOR CABLE CONFIGURATION



CASE	CURRENT
1	½KN DRIFT IN STILL WATER
2	½KN DRIFT OVER 1KN EDDY
3	0KN DRIFT OVER 1KN EDDY

SCALE: 1cm = 61 m (200 FT.)
DRILL WT = 28.3 Kg
$C_D xA = 0.153\ m^2$

FROM:
D. B. DILLON
5/79

Figure 2-14

2.6 THE LANDING SYSTEM

Initially it was believed that the arctic ADOM landing system would have to be designed to operate under the worst case condition of setting down in highly ridged zones as found in the Offshore Province (Section 2.2.3). Systems conceived to meet this requirement were complex indeed, and little confidence was felt for their success. Reviewing the distribution of pressure ridges with the assumption that multiyear ridges would not hinder the landing operation due to their low slope (<30^{o}) and well formed sails, indicated that 90% of the arctic ice cover from 0^{o} through 180^{o} longitude could be safely accessed by a relatively simple landing system (Section 2.2.3). In areas of high ridging intensity, as found in the Offshore Province, accessibility can be achieved with a probability of success greater than 75% by using pilot discretion when launching the ADOM system.

2.6.1 THE LANDER

A detail of the chosen Arctic ADOM system is shown in Figure 2-15 Illustrated in this figure are the major lander components; parachute assembly, impact absorbing torus, floatation material, as well as the recirculating jet drill, power cable, energy source, sensor cable, and electronics housings. Design of the torus allows omnidirectional impact absorbing capabilities while maintaining maximum landing impacts less than 100 g's. Figures 2-16 and 2-17 illustrate preliminary landing parameters. Note that all electronics are contained within watertight pressure housings in the event that the system should land in an open lead. Hydrostatic stability of the lander is assured by keeping the center of gravity low and the center of buoyancy high. This is achieved

in the lander design by placing the heavy energy source and cable assemblies on the bottom, electronic packages high and be filling the lander voids with foam.

Antenna deployments for data telemetry and navigation are simplified in this design. The same telemetry packaging and deployment techniques, as chosen for the open ocean ADOM, will be used in the arctic system. Contained in one or two of the electronic housings will be the antennas which will deploy straight up and out upon release of the parachute package.

Presently, the parachute assembly is identical to the one used on the open ocean ADOM system.

2.6.2 POTENTIAL SUPPORTING AIRCRAFT

Sizing of the ice ADOM lander is being held to a minimum. Table 2-5 summarizes preliminary lander specifications. Initial estimates indicate a possibility that a DeHavilland Twin Otter aircraft may be used as a vehicle for transporting and launching several arctic ADOM systems. Figure 2-18 illustrates a possible pre-launch position for the arctic ADOM in a Twin Otter.

As with the open ocean ADOM system, transportation and deployment can be readily accomplished using the C-130 transport aircraft.

ARCTIC ADOM SYSTEM

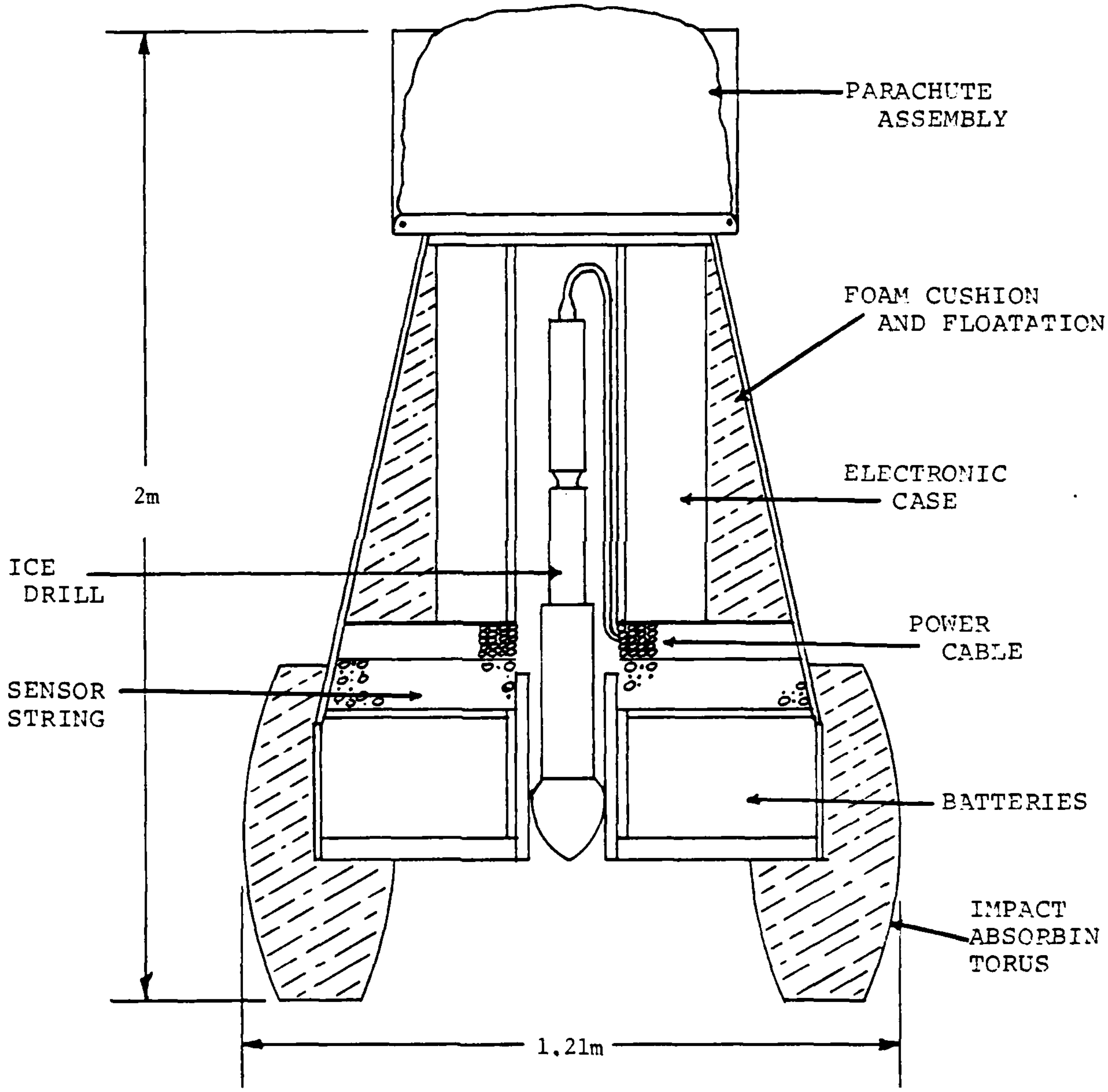
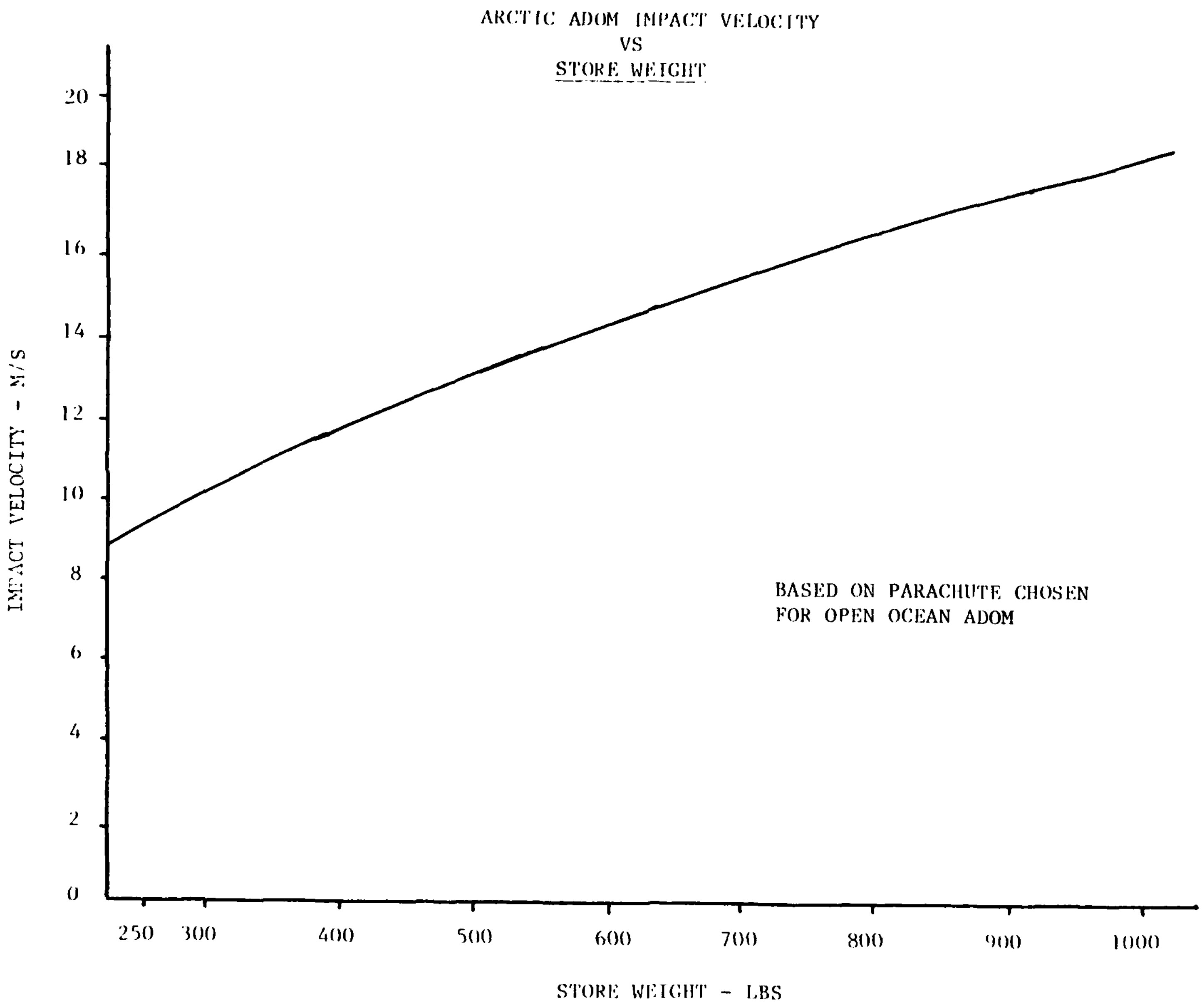


Figure 2-15



ARCTIC ADOM IMPACT VELOCITY
VS
STORE WEIGHT
IMPACT VELOCITY - M/S
20
18
16
14
12
10
8
6
4
2
0
250
300
400
500
600
700
800
900
1000
STORE WEIGHT - LBS
BASED ON PARACHUTE CHOSEN
FOR OPEN OCEAN ADOM

Figure 2-16

DECELERATION DISTANCE
VS
DECELERATION RATE

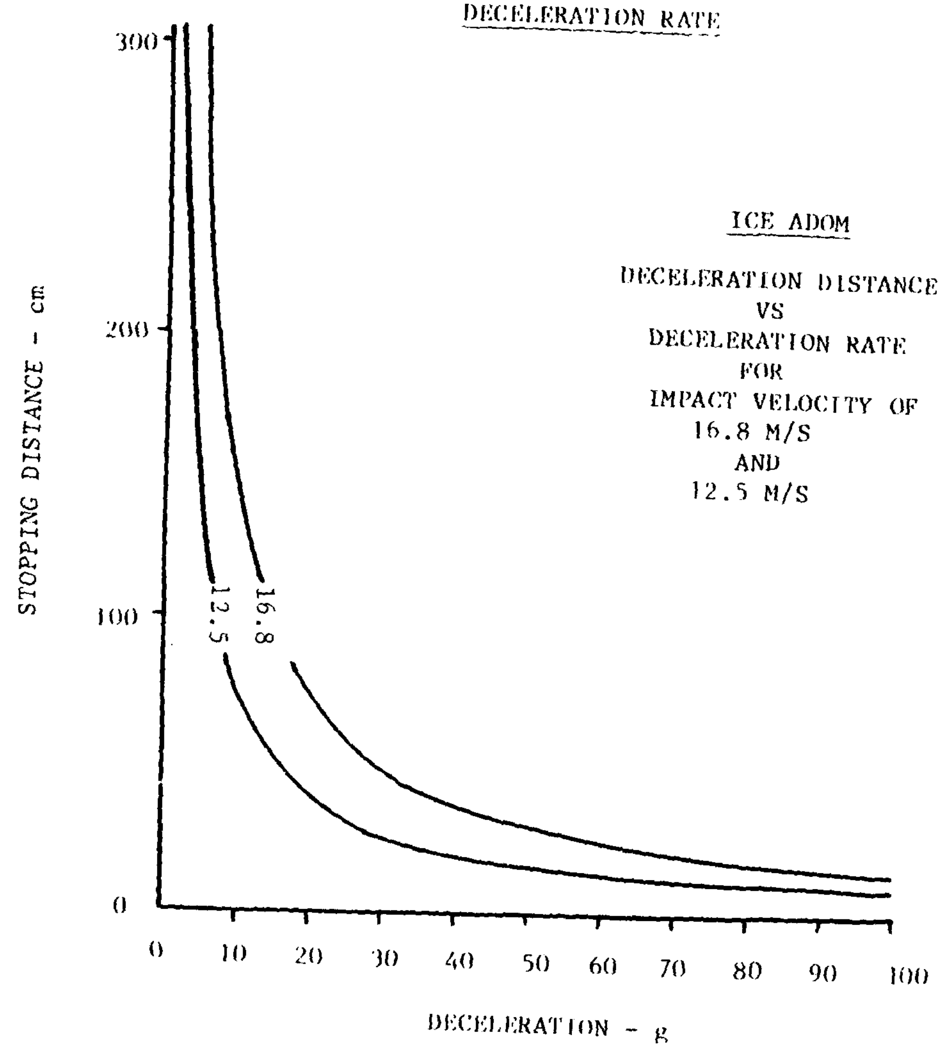


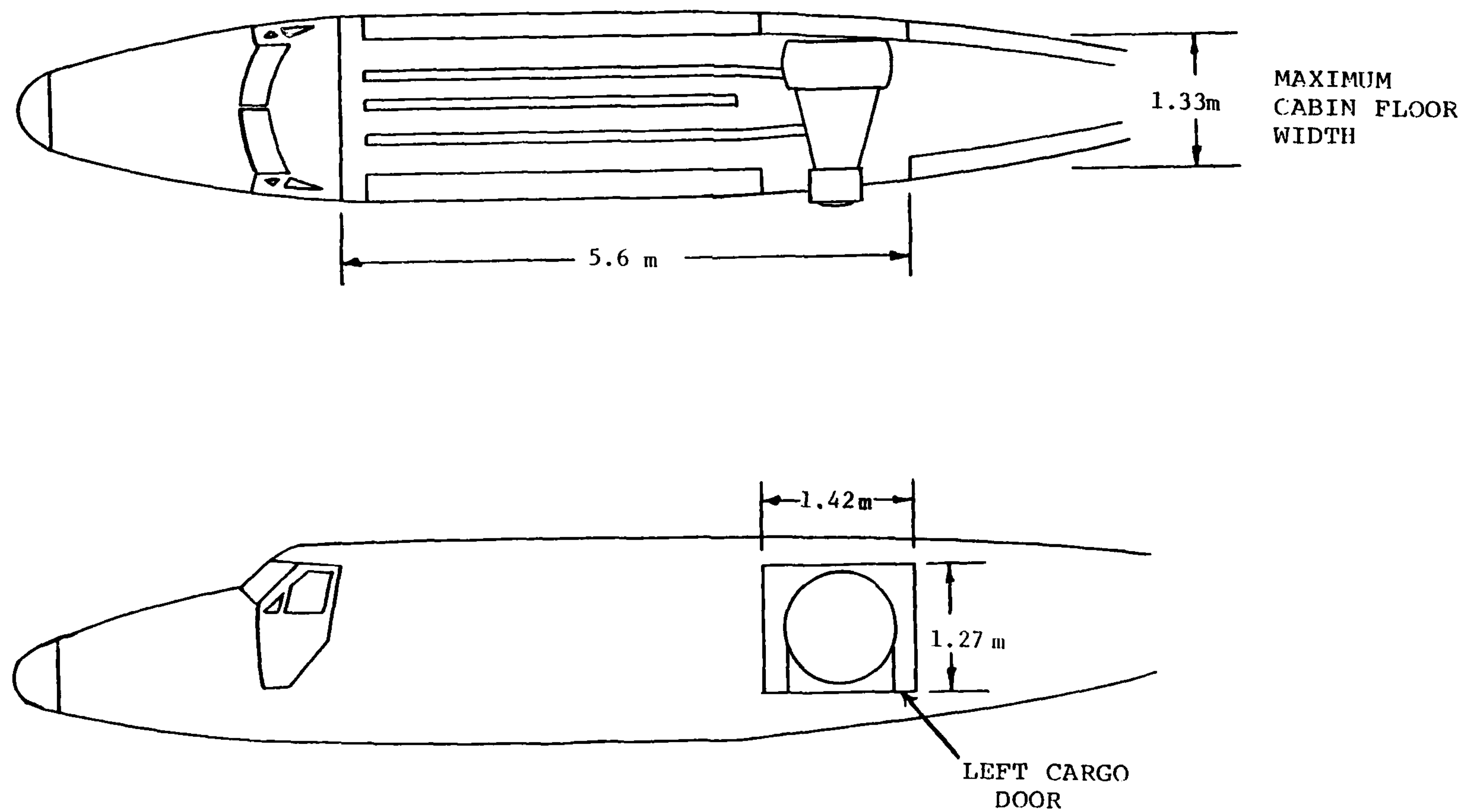
Figure 2-17

Table 2-5

PRELIMINARY ARCTIC LANDER SPECIFICATIONS

DIAMETER	1.21 m
HEIGHT	2.0 m
WEIGHT	453-680 KG
MAXIMUM IMPACT VELOCITY	12-17 m/s
MAXIMUM DECELERATION	100g

ICE ADOM DEPLOYMENT
VIA
DEHAVILLAND TWIN OTTER



MAX. LOAD DOOR SILL - 2200 KG

Figure 2-18

2.7 THE ADM COMPUTER CONTROL SYSTEM

The components that are included in the Arctic ADOM control system are shown in Figure 2-19. The processor, memory, power switches, and supporting circuitry are housed in a watertight enclosure located at the top of drill body. Control sensors are located at several key points in the drill body with power, cable payout mechanism and breakway power connector located in the lander. A communication port is provided at the lander allowing outside communication with the control processor.

The control system is being developed in two stages; 1) a very basic system requiring manual intervention to initiate the drilling sequence, and 2) a completely automated system requiring no manual intervention and containing system diagnostics.

2.7.1 PROCESSOR

The Intersil IM6100 CMOS microprocessor was selected for the arctic ADOM controller. System software will contain a small multitasking system to concurrently control the state of the system and output data to either the operator or a telemetry system. During automatic operation, control data is sampled every 100 milliseconds.

ARCTIC ADOM CONTROL SYSTEM

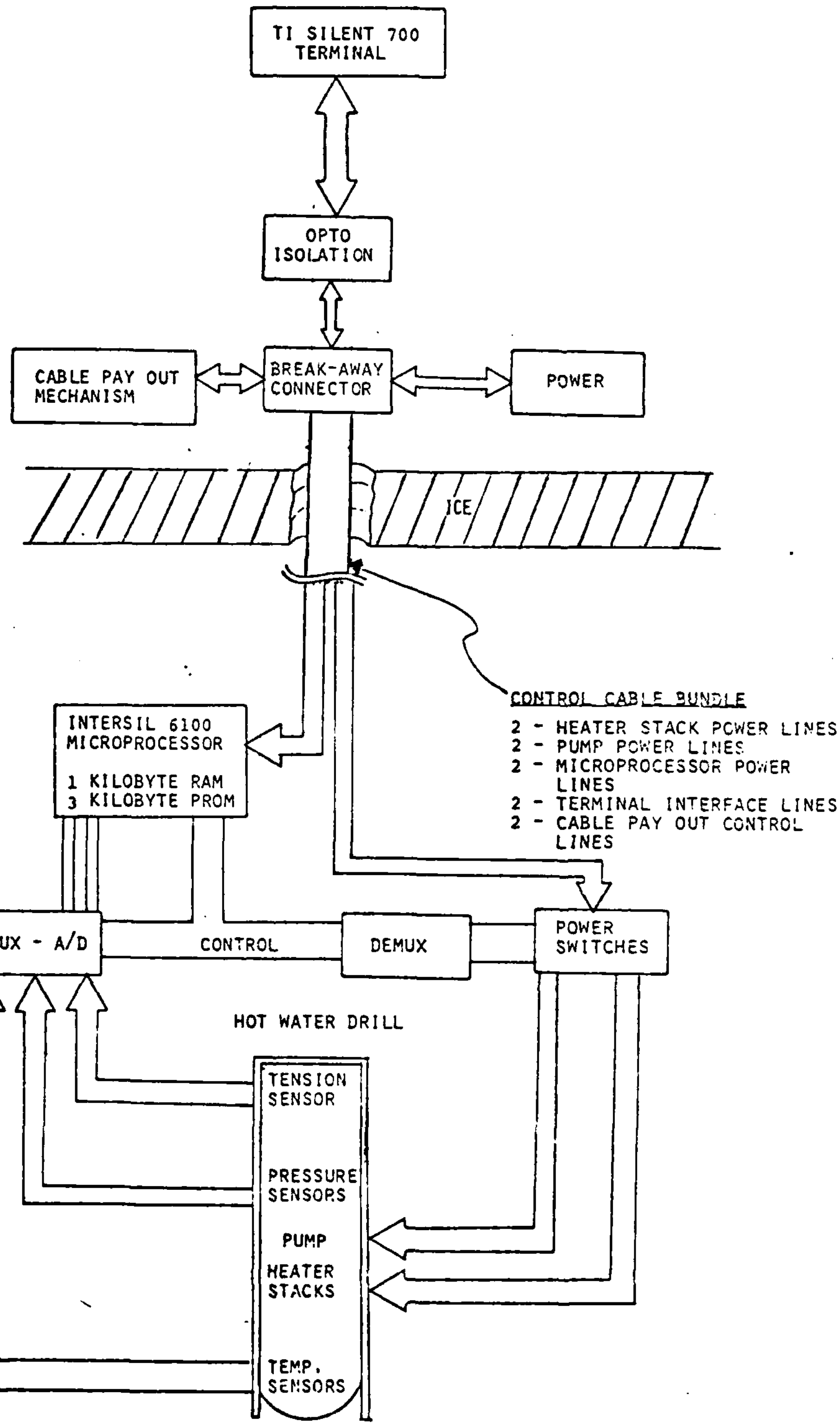


Figure 2-19

2.7.2 CONTROL SENSORS

Allowing the control system to adapt the drilling operation to the varying conditions of the arctic ice cover, requires a minimum of sensing capability. Three types of sensors are employed; tension, temperature, and pressure.

A tension sensor located at the cable/drill junction, measures the amount of cable tension at the drill. The control system continuously scans this tension and maintains a fixed percentage of the drill weight on the cable allowing the drill to gravity steer through the ice. Cable tension is maintained by stepping out appropriate lengths of cable from the lander.

Located in the parabolic hot point are redundant temperature sensors. The control system continuously scans these sensors and adjusts the power supplied to the hot point to maintain its temperature within acceptable limits. Without this control, the hot point could easily overheat and malfunction as it passes through the extremes of air and ice.

Two pressure sensors are utilized to provide information on the amount of melt water available for the jetting operation and to monitor the pumping flow rate. The two pressure sensors are located such that static head pressure outside the drill is measured by one sensor and pump output pressure inside the drill is measured by the second sensor. The amount of melt water produced by drilling with the hot point is easily related to the static head pressure, and by monitoring this pressure, the controller can decide when to initiate the more efficient jet drilling operation knowing that the pump is adequately primed.

Using the two pressure sensors in a differential mode allows the controller to monitor the flow rate of melt water through the internal heating chamber. Too low a pressure difference indicates that melt water is being lost, and that power to the heaters must be removed to prevent damage from over heating. Too high a pressure difference indicates temperatures are rising and that power to the heaters must be removed to prevent damage from overheating.

2.7.3 COMMUNICATION

Developing a successful drilling system requires a means to monitor and control the system's performance insitu. This ability to manually monitor and control the drilling operation is provided via a communication port located on the drill and on the lander. Through this communication port, an operator can communicate directly with the drill's computer via a terminal.

At the computer terminal, the operator can initiate the automated drilling sequence, automatically monitor the drilling operation at one second intervals, and override automatic control with manual commands.

2.7.4 FAILSAFE ASPECTS

To increase the probability of successfully penetrating the ice cover, several approaches have been taken:

- . Development of an active, intelligent control system.
- . Where possible, the use of redundant sensors.
- . Parallel banking of heaters.
- . Ability to make several attempts to an operation before initiating backup routines.
- . Development of backup routines, such as:
  - drilling through the ice cover with the hot point should a failure in the pumping system occur.
  - drilling at reduced power levels should failures occur in critical sensors.
  - continually rechecking for possible continuation of normal operations.

2.8 THE ENERGY SYSTEM

As previously estimated and verified through experimentation, approximately 37 KWH of energy is required to penetrate 15.2 m of ice with a 15 cm diameter hole (26 KWH for 10.6 m of ice). To obtain this required level of energy in a battery of reasonable size and weight, is presently only possible by using a system based on lithium technology. For this reason, considerable effort has been expended in reviewing lithium based battery technology.

2.8.1 CURRENT LITHIUM TECHNOLOGY

Table 2-6 summarizes some of the more popular lithium battery types and their general specifications. The three cells showing the greatest potential; $LiSO_2$, $LiSOCl_2$, and the lithium/water cell, are discussed in greater detail in the following sections. Safety aspects of all lithium cells are of utmost concern and manufacturers are rigorously persuing this aspect of the technology.

Lithium Sulfur Dioxide (SO_2)

This battery is generally used for active or reserve duty and is the most popular chemistry in use today. The principle configuration is cylindrical, hermetically sealed and requires a safety vent. Capacities ranging from 700mA hr to 160A hr are possible. Loads must be applied to the cell gradually to minimize passivation of the cell plates. Temperature and high discharge deratings can each be as high as 50%. Under high discharge rates, internal heating of the battery becomes significant, and if not controlled, can lead to battery failure through venting. Stacking cells to form the required ADOM power supply increases the difficulty of controlling the heat generated by the batteries and decreases the system reliability.

Lithium Thionyl Chloride ($SOCl_2$)

As with the SO_2 battery, this battery is generally used for active or reserve duty. Varying cell configurations can be achieved with capacities ranging from 360mA hr to 17,000A hr. Materials making up the cell are less expensive than materials used in the SO_2 cell, however, volume production of this cell type is not as great as with the SO_2 cell, hence its price is still high. Current densities are high (5-10m/cm^2) allowing better performance than the SO_2 cell when subjected to high current drain.

Present storage capabilities are limited with activated cells; generally less than 6 months with projections indicating that storage of 1 year will be possible within 3 years. However, storage of these cells in the unactivated condition is indefinite as the electrolyte is kept in a separ-are container and added to the cell only when activation is desired.

<u>Lithium/Water Cell</u>

The lithium/water cell uses a solid lithium anode in an aqueous solution containing hydroxyl ions. One type of cell, called the Power cell, is manufactured by The Continental Group, Inc, New York, NY. Unique advantages of this cell are:

- Very high energy density.
- Externally introduced reactant, insuring long shelf life and making transportation safer.
- Modules can be disassembled for inspection.
- Refurbishable by replacing expended anodes.

Figure 2-20 illustrates the electrochemical characteristics of the lithium/water Power Cell. Of the 3820 Whr of energy released per pound of lithium consumed during the reaction, up to 2500 Whr per pound of lithium can be delivered by the cell, the remaining energy being released as heat.

A basic modification of the Power Cell produces a lithium-water-hydrogen peroxide couple which nearly doubles the open circuit voltage and the theoretical energy density.

The only changes required from the basic lithium/water system are the addition of a thin silver or palladium plating to the iron screen cathode and a system for introducing the peroxide solution to the main electrodyte stream as required by power demands on the battery. To re-duce the amount of water consumed by the cell in non-marine application,

a method for precipitating lithium out of solution in the form of an insolable carbonate or salt is employed. Without this technique, about 90Kg (200 lb) of water per kilowatt day would be required for the lithium-water-hydrogen peroxide system.

Figure 2-20 illustrates the electrochemical characteristics of the lithium-hydrogen peroxide cell. Of the 6980 WHR of energy released per pound of lithium consumed during the reaction, up to 4350 WHR can be delivered per pound of lithium by the cell, the remaining energy released as heat. Approximately 2 Kg of 80% peroxide is required for each pound of lithium.

	BATTERY TYPE				
	Li V_2 O_5	Li SO_2	Li $SOCl_2$	Li/Water	Li/Water/H_2O_2
Watt Hours/lb.	120	140	300	500-2500	2000-5000
Watt Hours/in^3	11	8	18	-	-
Nom. OCV	3.42	2.90	3.60	-	-
Nom. CCV	3.00	2.75	3.30	1.0-1.5	2.2-2.6

GENERAL LITHIUM BATTERY SPECIFICATIONS

Table 2-6

ELECTROCHEMICAL CHARACTERISTICS

OF THE

LITHIUM/WATER POWER CELL

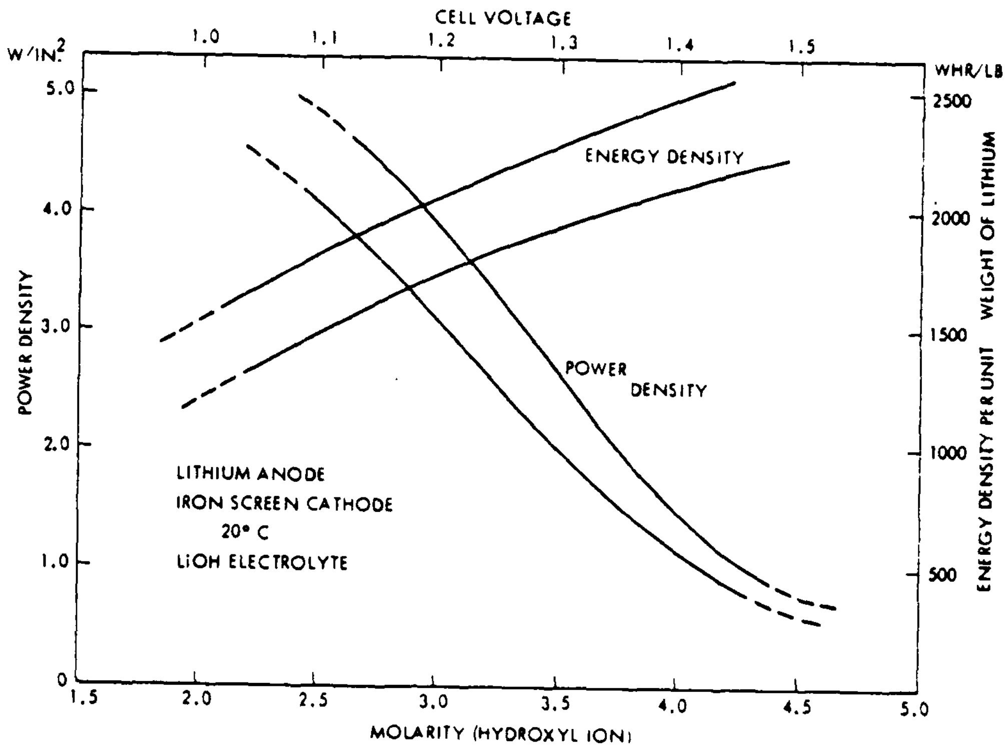


Figure 2-20

ELECTROCHEMICAL CHARACTERISTICS
OF THE
LITHIUM-HYDROGEN PEROXIDE CELL

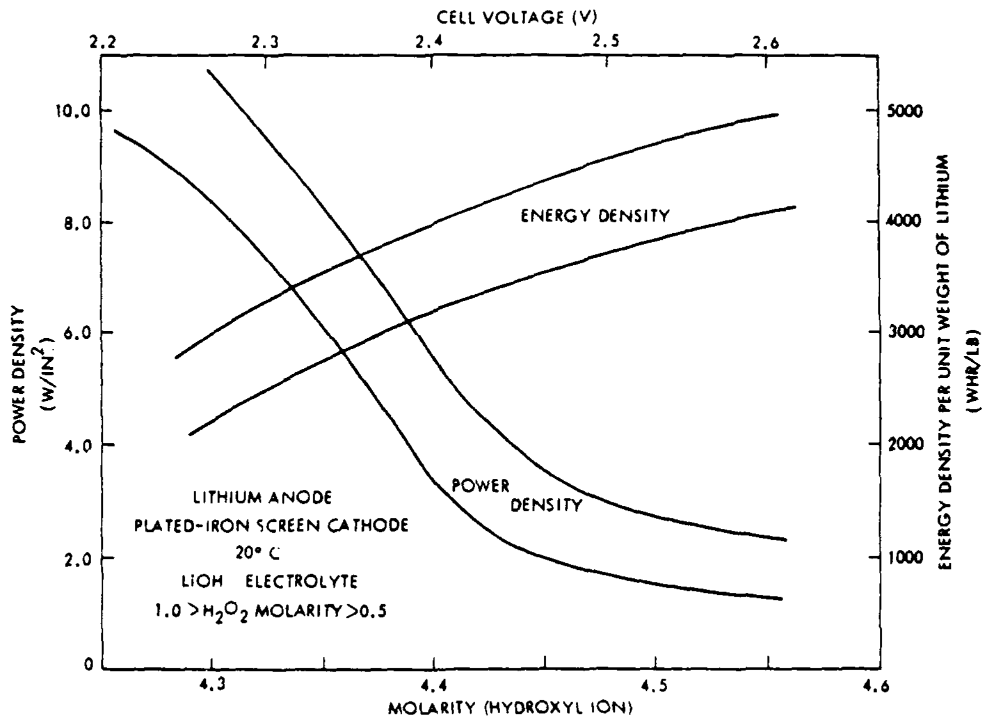


Figure 2-21

2.8.2 HIGH DISCHARGE TESTING OF Li SO_2 BATTERIES

A limited number of tests were performed to provide an indication of the performance of Li SO_2 batteries under high rates of discharge and at temperature extremes. Two types of cells were tested; the Mallory LO5OS and the PCI 660-5AS. Results of the testing verified that the batteries must be derated if used at low temperatures (-40°C) or artificially maintained at approximately 20°C prior to discharge to obtain maximum energy output. Battery temperature rises considerably above ambient temperatures under high discharge rates. Monitoring this temperature could possibly allow controlled high rate discharge from the batteries, decreasing the chance of battery failure by venting as witnessed in short circuit tests. Drilling rate can be matched to an optimum high discharge battery rate to obtain maximum efficiency from the battery power supply.

2.8.3 CONCLUSION

Lithium battery technology does exist to furnish Arctic ADOM with a battery operated power supply. Most manufacturers of lithium based batteries supply small cells using lithium sulfur dioxide (SO_2) chemistry. Although the energy density of sulfur dioxide cells is high, the substantial number of individual cells required to supply the 26-37 KWH of energy required for ADOM, makes this approach unrealistic. Therefore, a specific battery system designed and fabricated to Arctic ADOM specifications is required. Primary candidates are Thionyl Chloride and lithium-water hydrogen peroxide due to their higher energy densities. The two leading manufacturers who have the capability to design, fabricate, and test a battery power to Arctic ADOM specifications are currently Honeywell Power Sources Center ($LiSOCl_2$) and The Continental Group, Inc. (Lithium/Water).

Table 2-7 summarizes the preliminary battery pack requirements and Figure 2-22 illustrates the estimated power profile for the battery pack.

ADOM BATTERY REQUIREMENTS

Total Energy Requirement (10.6m hole)	26 KWHR
Total Energy Requirement (15.2m hole)	37 KWHR
Power Output	12 KW - 36 KW
Nominal Operating Voltage	350VDC
Volume	$\sim 0.11 m^3$
Nominal Weight	182Kg
Nominal Diameter [1]	86cm
Maximum Acceleration on Impact	100g
Minimum Outside Temperature [2]	$-40^{o}C$

NOTES

1. Battery pack must have provision for running the ice drill through the pack, on the center line. Clearance hole diameter required is 18cm.

2. Battery pack can be heated to optimum operating temperature prior to operation and then convection cooled to maintain satisfactory operating temperature.

3. Turn on time for the battery pack is considered slow, on the order of 10 msec.

4. Safety is of utmost concern. Every possible measure must be taken to insure safety in storage handling, transportation and operation. Complete operational procedures must be prepared and observed. It is expected that the battery manufacturer and the Marine Systems Engineering Laboratory of the University of New Hampshire will work closely to establish satisfactory safety requirements and guidelines.

Table 2-7

ESTIMATED DRILLING POWER PROFILE

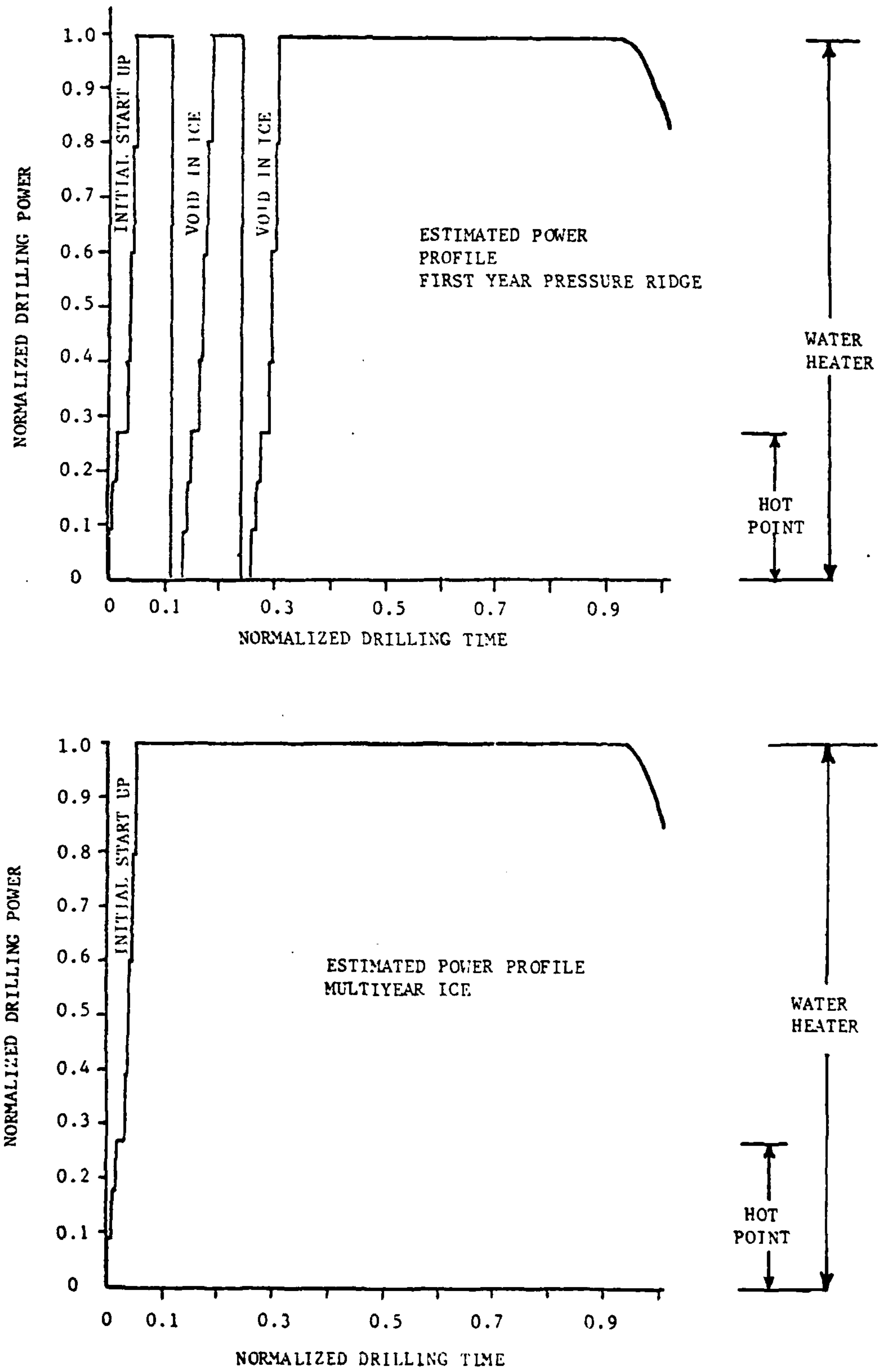


Figure 2-22

2.9 NAVIGATION

Provision must be made to locate the ADOM, once it is deployed on the ice. Since much of the ice pack is in motion, it is also necessary periodically to measure and report its current geodetic position. While system recovery is unlikely, the data the ADOM may generate can be located and also it may be desirable to revisit the station for various reasons.

The requirements on the Navigation system include:

- Accuracy - Probable error 2000 meters
- Power Demand - Absolute minimum, with computer programmable operation
- Data Recovery - Data recovered at the Control Center, and not in the ADOM
- Antenna - Upward looking cone desirable, circular polarization desirable, simple design essential
- Data Sampling Rate - Once or twice a week

There are several potential solutions to the ADOM navigation problem, including:

Aircraft - A radar reflector on the ADOM, or a beacon, would permit an aircraft to locate the ADOM's position relative to itself. The aircraft would then have to carry equipment for fixing its own position and for converting the measured data to geodetic coordinates.

Satellite Transponder - The NAV STAR, and Global Positioning Systems will permit a station with an appropriate transponder to measure its location to within tens of feet. The system generally does not report the measured position back to a System Control, as required in ADOM; the accuracy obviously exceeds the requirement; the transponder, currently, is quite expensive; and the power drain is relatively high, especially if

the receiver must remain on for appreciable time in order to capture satellite passes.

NIMBUS 6 Systems - Successful location has been achieved for years on air-dropped buoys in the Arctic, using the NIMBUS 6 satellite. A precision oscillator in the buoy is received by the satellite, the doppler signal extracted and the time of null retransmitted to the ground. Lines of position are computed, through multiple passes, with an ultimate probable error of about one half mile.

The NIMBUS 6 is due to burn-up within a year, terminating this system. Reliable hardware has been developed for this system.

ARGOS - The ARGOS satellite, a cooperative US/French system based on the TIROS rocket, is currently operational, with two satellites in polar orbits. They are sun stabilized, thus crossing the equator at precisely the same time on each pass each day. In the Arctic Ocean region, 28 passes per day may be expected. The system is designed to serve 16,000 users, providing location, and a limited amount of data transmission. The data is stored, and spit out on command over a data reduction station, nominally Wallops Island. Position fixes with a 99% probability are specified as 3000 meters. Higher accuracies are available if a stable heat sink is available.

Each platform may transmit, at will, for no longer than one second, providing an identification code, and if desired, a series of data of communication words in each 3 minute epoch. The transmit frequency is controlled precisely at 401.65 mHz. The doppler null is observed and its time of occurance recorded for later recovery.

The ARGOS system is available to the program in the form of certified system elements. For ADOM, the system appears to consist of two printed

circuit boards, 9.8 inches long, and 3.3 inches wide, plus an antenna. Power at 16 to 35 volts DC is needed. The system takes 700ma when transmitting, and generates about 3 watts of RF.

Components are apparently available from ARGOS at costs listed in June 1979 as:

Electronics	$ 3,000
Antenna (simplest)	150
Total (approx.)	$ 3,150

There are other operational cost incurred related to data reduction when the system collects data, or makes position measurements. At the rate of one or two position fixes per week, these further costs are trivial.

Recommendations

It is recommended that components and services of ARGOS be used for position determination in the Air-droppable version of the Arctic ADOM.

2.10 CONCLUSIONS

The completion of MSEL's second year efforts provide an Arctic ADOM system design and preliminary ice penetrating hardware. The design and hardware show a great potential for success in meeting Project ADOM's goals.

Key findings are summarized below:

- Model testing verified that approximately 37 KWHR of electrical energy is required to penetrate 15.2 m of ice with a 15 cm diameter hole. 26 KWHR is required to penetrate 10.6 m of ice.
- The recirculating water jet drill is an effective and thermally efficient ice penetrating system and well adopted to unmanned computer controlled operations.
- Lithium batteries are presently the best energy source available and drill speed can be designed to match battery power output for greatest efficiency of energy transfer.
- A simple landing system can be devised to provide accessibility to more than 90% of the arctic ice cover.
- The DeHavilland Twin Otter, as well as the much larger C-130, can be used as the vehicle for air launching the arctic ADOM system.

SECTION III

FUTURE ACTIONS

Figure 3-1 shows the Milestone Chart of the program while Figure 3-2 details specifically the program as planned for the next two years, March 1980 to March 1982.

The following specific tasks are proposed for the third year program.

. Complete the basic control system software and computer development initiated in the second year program. This is the very basic control system which will allow unmanned operation of the arctic ADOM drilling system.

. Initiate the final control system software which will contain diagnostic support adding greater reliability to the unmanned drilling operation.

. Construct two Advanced Development Models of the recirculating water jet drill incorporating the latest engineering improvements and refinements determined through the extensive testing program completed in the second year's efforts. These two drilling systems will be designed for unmanned, computer controlled operation.

. Finalize the design for the ADOM ice lander with interfacing all system components considered.

. Initiate development and fabrication of the ice lander. Testing of various aspects of the lander will be initiated at this time also. Two systems will be constructed.

. Finalize the design and select manufacturer for the battery energy source.

The following specific tasks are proposed for the fourth year program.

. Complete the final control system software with diagnostics and incorporate with the ADM ice drill system.

- Test the ADM drill system in the computer control mode at the US Army Cold Regions Research and Engineering Laboratory, Hanover, NH.
- Complete the fabrication of the ice ADOM landing system and perform limited dummy drop tests.
- Complete final system interfacing including sensor cable, data acquisition system, and navigation systems.
- Perform a full scale landing, drilling and limited cable deployment test program at the University's Lake Winnipesaukee field facility during the winter of 1982. It is anticipated that the landing system will be dropped from a fixed structure, such as a crane, rather than an aircraft. Drop height will be chosen to adequately simulate parachute impact velocities.
- Upon completion of successful Winnipesaukee drop tests, the fourth year program will come to a close with an appropriate non-arctic site chosen and a full scale aircraft launched ADOM test performed.

The fifth year program will consist of preparations for the completion of a total arctic test of ADOM. Completion of these tests will bring us to a point of critical decision for the ADOM Committee, and for ONR, with several choices for continuing the program effort.

2 YEAR ADOM PROGRAM MILESTONES

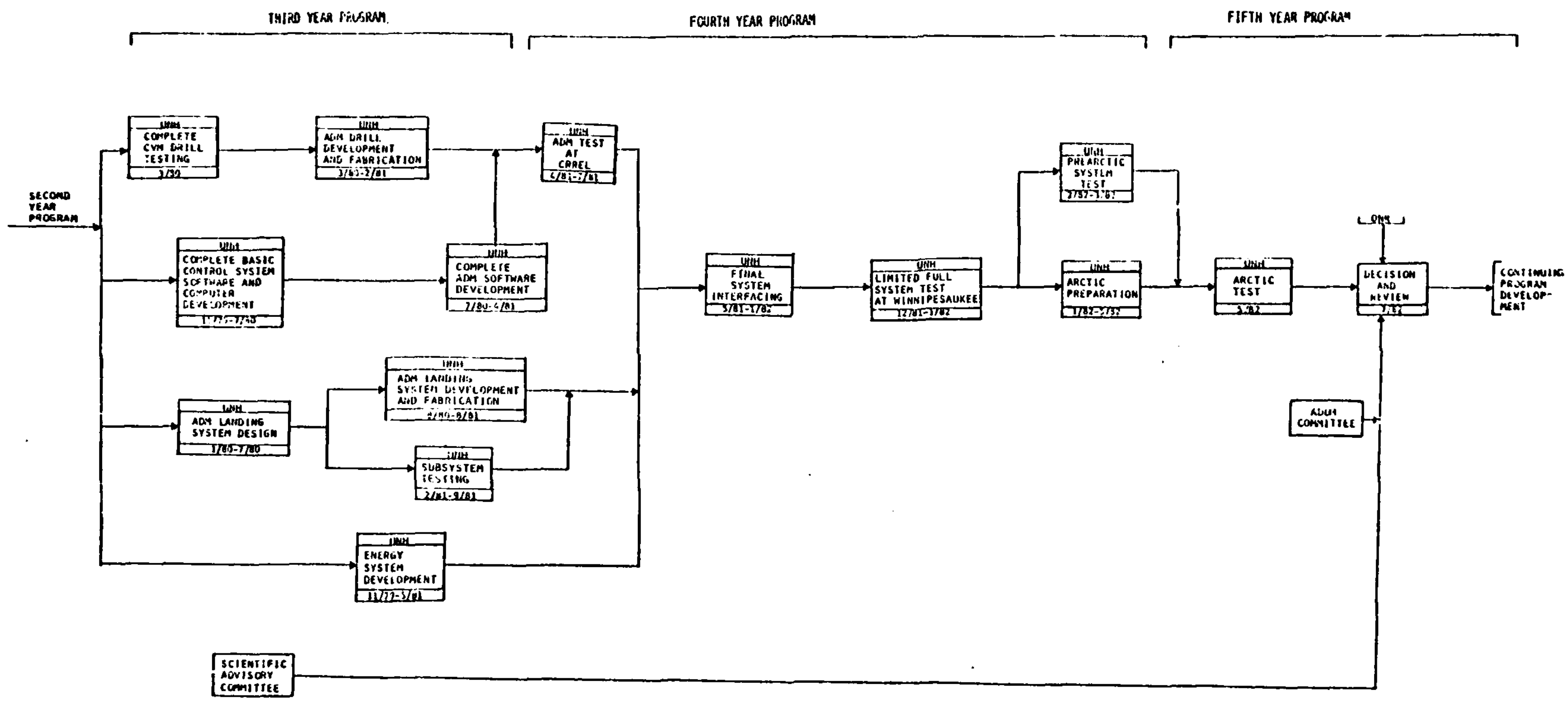


Figure 3-1

ADOM TIMELINE

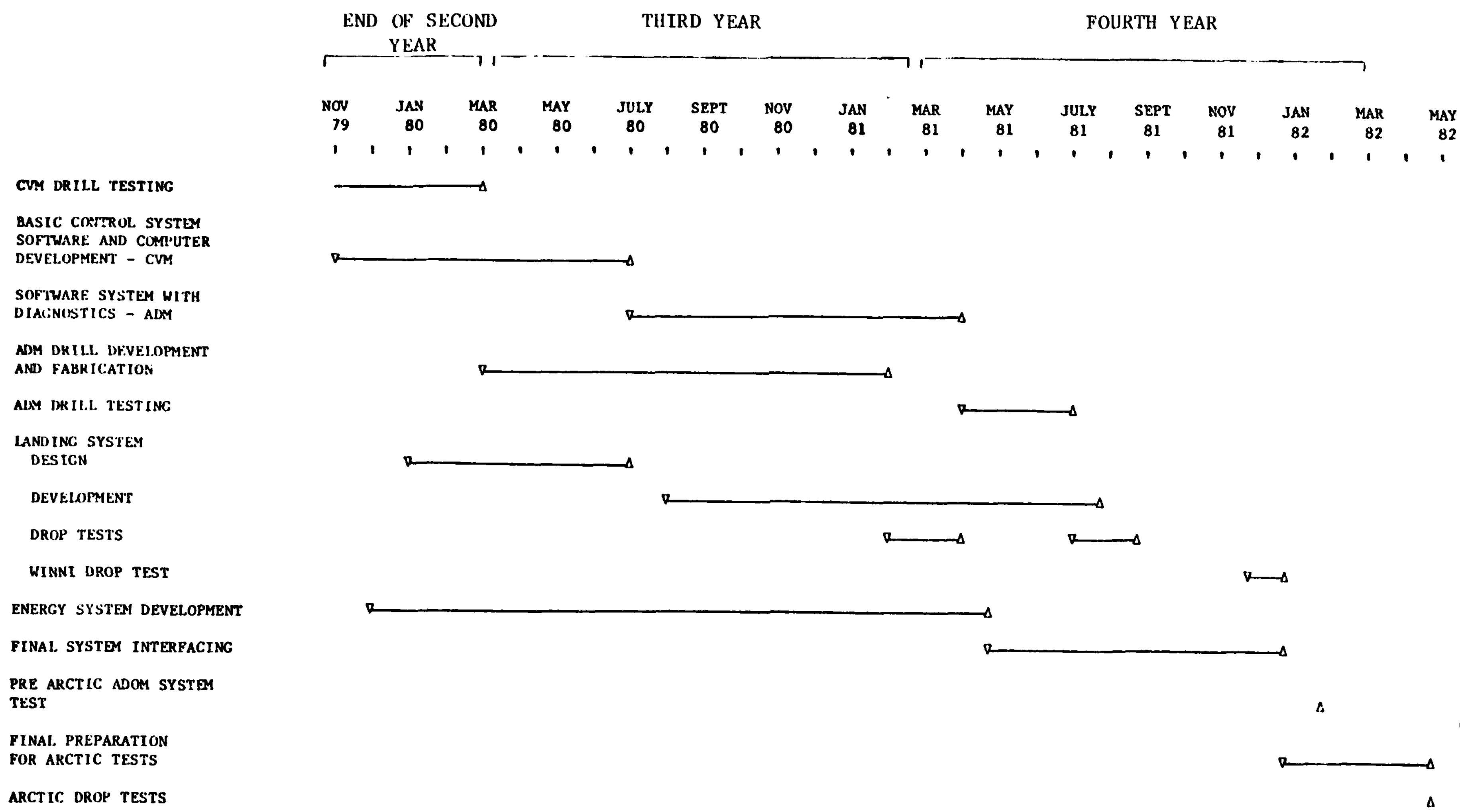


Figure 3-2

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6. Gilpin, R. R., The Ablation of Ice by a Water Jet, Transactions of the CSME, Vol. 2, No. 2, 1973-74, pp. 91-96.

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APPENDIX A

Preliminary Analysis of Ice-ADOM Suspension Configurations

D. B. Dillon
11 May 1979

The 1978 ADOM progress report (April 1979) defines two current profiles for ICE-ADOM (report figure 1-2). One shows an ICE-ADOM suspended from fast ice (not moving), over a 1 knot current centered at a depth of 150 m. The second assumes the ice is wind blown at a speed of 1/2 knot against the sub-surface eddy. A third possibility is obvious - the wind blown floe in still water.

Cable configurations have been calculated for these three cases, assuming a drag coefficient of 1.2 for the 62.4 lb immersed-weight probe, and 1.8 for the 75 feet of .5-inch power cable and the 1000 meters of 0.172 inch array cable. Drag of the sensor modules was neglected.

Four primary effects of the current are apparent:

(1) to sway the probe horizontally from beneath the bore-hole in the ice,
(2) to lift the probe above its maximum depth below the bore hole,
(3) to tilt the array from the vertical , and
(4) to bend the array cable from a straight line.

These effects are summarized as follows:

Case	Current	Sway (Ft)	Rise (Ft)	Tilt (Deg)	Bend (Deg/1000M)
1	1/2 Kt drift in still water	776.5	98.5	11	13
2	1/2 kt drift over 1 kt eddy	948.5	172.3	18	27
3	0 kt drift over 1 kt eddy	24.0	0.7	2	4

The remaining tables show the configuration and tension for the three cases as well as the input data used for the calculations.

PROBE CD*A (SQFT): 1.65
WEIGHT (LB): 62.4
CURRENT @ PROBE (KT): 0
PROBE TILT (DEG): 0
PROBLEM: ICE ADOM PROBE SUSPENSION MAY, 1979 D.B.DILLON
INITIAL CONDITION: THERMAL DRILL
CURRENT PROFILE: NO MOTION OVER SUBSURFACE EDDY
CABLE IDENTIFICATION: 75 FT .5 IN POWER CABLE + 1000 M .172 IN. ARRAY

SCOPE	X	Y	Z	TENSION	PHI	THETA	STR.SCOPE	STEPS
.00	.00	-3355.13	.00	62.40	90.00	.00	.00	0
15.00	.00	-3340.13	.00	62.89	90.00	.00	15.00	1
30.00	.00	-3325.13	.00	63.38	90.00	.00	30.00	2
45.00	.00	-3310.13	.00	63.87	90.00	.00	45.00	3
60.00	.00	-3295.13	.00	64.36	90.00	.00	60.00	4
75.00	.00	-3280.13	.00	64.85	90.00	.00	75.00	5
575.00	.00	-2780.13	.00	85.69	90.00	.00	575.00	6
1075.00	.00	-2280.13	.00	106.52	90.00	.00	1075.00	7
1575.00	.00	-1780.13	.00	127.36	90.00	.00	1575.00	8
2075.00	.00	-1280.13	.00	148.19	90.00	.00	2075.00	9
2206.83	.00	-1148.30	.00	153.69	90.00	.00	2206.83	10
2575.00	.11	-780.13	.00	169.03	90.13	.00	2575.00	17
3075.00	5.39	-280.20	.00	189.91	87.43	.00	3075.00	26
3163.23	10.49	-192.12	.00	193.60	85.89	.00	3163.23	30
3191.39	12.50	-164.04	.00	194.77	85.92	.00	3191.39	31
3355.83	24.00	.00	.00	201.61	86.05	.00	3355.83	32

?

PROBE CD*A (SQFT): 1.65
WEIGHT (LB): 62.4
CURRENT @ PROBE (KT): .5
PROBE TILT (DEG): 1.0736

PROBLEM: ICE ADOM PROBE SUSPENSION MAY, 1979 D.B.DILLON
INITIAL CONDITION: THERMAL DRILL
CURRENT PROFILE: 1/2 KNOT DRIFT AGAINST 1 KNOT SUBSURFACE EDDY
CABLE IDENTIFICATION: 75 FT .5 IN POWER CABLE + 1000 M .172 IN. ARRAY

SCOPE	X	Y	Z	TENSION	PHI	THETA	STR.SCOPE	STEPS
.00	.00	-3183.55	.00	62.39	88.93	.00	.00	0
15.00	.38	-3168.56	.00	62.88	88.21	.00	15.00	2
30.00	.94	-3153.57	.00	63.38	87.50	.00	30.00	4
45.00	1.68	-3138.59	.00	63.87	86.81	.00	45.00	6
60.00	2.61	-3123.62	.00	64.37	86.13	.00	60.00	8
75.00	3.71	-3108.66	.00	64.86	85.45	.00	75.00	10
575.00	66.75	-2612.80	.00	85.57	80.54	.00	575.00	21
1075.00	162.43	-2122.10	.00	106.06	77.63	.00	1075.00	28
1575.00	278.18	-1635.71	.00	126.38	75.73	.00	1575.00	32
2075.00	407.38	-1152.71	.00	146.55	74.40	.00	2075.00	35
2079.58	408.61	-1148.30	.00	146.73	74.39	.00	2079.58	36
2575.00	562.73	-677.73	.00	166.48	67.69	.00	2575.00	51
2780.37	650.42	-492.13	.00	174.35	61.43	.00	2780.37	64
3075.00	800.01	-238.40	.00	185.04	57.85	.00	3075.00	74
3355.83	948.46	-.01	.00	195.00	58.75	.00	3355.83	82

?

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ICE ADOM PROBE SUSPENSION MAY, 1979 D.B.DILLON
INITIAL CONDITIONS:
       TX          TY          TZ          X          Y          Z     IDENTIFICATION
      .000       62.400       .000       .000  -3355.800      .000   THERMAL DRILL

FLUID PARAMETERS:
PROFILE  1   NAME  NO MOTION
LAYER SPEED        DENSITY     KIN. VISC.     Y(TOP)      ANGLE  SPEED GRAD. ANGLE GRAD.
   1   .0000E+00  1.9905E+00  1.2817E-05  1.0000E+05      .000   .0000E+00   .0000E+00

PROFILE  2   NAME  1/2 KNOT DRIFT IN STILL WATER
LAYER SPEED        DENSITY     KIN. VISC.     Y(TOP)      ANGLE  SPEED GRAD. ANGLE GRAD.
   1  5.0000E-01  1.9905E+00  1.2817E-05  1.0000E+05      .000   .0000E+00   .0000E+00

PROFILE  3   NAME  NO MOTION OVER SUBSURFACE EDDY
LAYER SPEED        DENSITY     KIN. VISC.     Y(TOP)      ANGLE  SPEED GRAD. ANGLE GRAD.
   1   .0000E+00  1.9905E+00  1.2817E-05 -1.1483E+03      .000   .0000E+00   .0000E+00
   2  1.0000E+00  1.9905E+00  1.2817E-05 -1.9212E+02      .000  1.5240E-03   .0000E+00
   3   .0000E+00  1.9905E+00  1.2817E-05 -1.6404E+02      .000 -3.0480E-03   .0000E+00
   4   .0000E+00  1.9905E+00  1.2817E-05  1.0000E+05      .000   .0000E+00   .0000E+00

PROFILE  4   NAME  1/2 KNOT DRIFT AGAINST 1 KNOT SUBSURFACE EDDY
LAYER SPEED        DENSITY     KIN. VISC.     Y(TOP)      ANGLE  SPEED GRAD. ANGLE GRAD.
   1  5.0000E-01  1.9905E+00  1.2817E-05 -1.1483E+03      .000   .0000E+00   .0000E+00
   2  1.5000E+00  1.9905E+00  1.2817E-05 -4.9212E+02      .000  1.5240E-03   .0000E+00
   3   .0000E+00  1.9905E+00  1.2817E-05   .0000E+00      .000 -3.0480E-03   .0000E+00
   4   .0000E+00  1.9905E+00  1.2817E-05  1.0000E+05      .000   .0000E+00   .0000E+00

CABLE PARAMETERS:
CABLE  1   NAME  75 FT .5 IN POWER CABLE + 1000 M .172 IN. ARRAY
SEG. DIAMETER     AIR WGT.    WATER WGT.   LENGTH      INTERVAL    ELAS. LOAD. CN        CT/CN      CS/CN
  1  5.0000E-01  3.2730E-02  3.2730E-02  7.5000E+01  1.5000E+01     1     1  1.80E+00  5.00E-03    .00E+
  2  1.7200E-01  4.1670E-02  4.1670E-02  3.2808E+03  5.0000E+02     1     1  1.80E+00  5.00E-03    .00E+

OPTION LIST:
LOOP: 4    SUPPRESSION: 3    FORMAT: 0    PLOT: 0
NEXT PHASE CODE; ZERO FOR HELP?
```

```
PROBE CD*A (SQFT):           1.65
     WEIGHT (LB):            62.4
CURRENT @ PROBE (KT):        .5
PROBE TILT (DEG):            1.0736
            PROBLEM: ICE ADOM PROBE SUSPENSION MAY, 1979 D.B.DILLON
  INITIAL CONDITION: THERMAL DRILL
    CURRENT PROFILE: 1/2 KNOT DRIFT IN STILL WATER
CABLE IDENTIFICATION: 75 FT .5 IN POWER CABLE + 1000 M .172 IN. ARRAY
```

SCOPE	X	Y	Z	TENSION	PHI	THETA	STR.SCOPE	STEPS
.00	.00	-3257.25	.00	62.39	88.93	.00	.00	0
15.00	.38	-3242.25	.00	62.88	88.21	.00	15.00	2
30.00	.94	-3227.26	.00	63.38	87.50	.00	30.00	4
45.00	1.68	-3212.28	.00	63.87	86.81	.00	45.00	6
60.00	2.61	-3197.31	.00	64.37	86.13	.00	60.00	8
75.00	3.71	-3182.35	.00	64.86	85.45	.00	75.00	10
575.00	66.75	-2686.50	.00	85.57	80.54	.00	575.00	21
1075.00	162.43	-2195.79	.00	106.06	77.63	.00	1075.00	28
1575.00	278.18	-1709.40	.00	126.38	75.73	.00	1575.00	32
2075.00	407.38	-1226.40	.00	146.55	74.40	.00	2075.00	35
2575.00	546.18	-746.06	.00	166.61	73.43	.00	2575.00	38
3075.00	692.10	-267.83	.00	186.58	72.69	.00	3075.00	40
3355.83	776.54	.00	.00	197.77	72.34	.00	3355.83	41

?

SELECT PROFILE (0=STOP, 2, 3, OR 4)?3

3355.83	[illegible]	97.62	.00	[illegible]	84.04	.00	3355.83	[illegible]